Benthic Macroinvertebrate Study of the Greater Lake Washington and Green-Duwamish River Watersheds Year 2002 Data Analysis

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King County

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
BI	Biotic Index
B-IBI	Benthic Index of Biological Integrity
BMEP	Basin Management Evaluation Program
BOD	Biological Oxygen Demand
CFU	Colony Forming Units
CTI	Community Tolerance Index
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EPT	Ephemeroptera, Plecoptera, Trichoptera
EVS	EVS Environment Consultants
FFG	Functional Feeding Group
GIS	Geographic Information System
HBI	Hilsenhoff Biotic Index
MS	Microsoft
NTU	Nephelometric Turbidity Units
QA/QC	Quality Assurance / Quality Control
RBP	Rapid Bioassessment Protocol
SAP	Sampling and Analysis Plan
SWDI	Shannon-Weiner Diversity Index
EIA	Effective Impervious Area
TOC	Total Organic Carbon
TSS	Total Suspended Solids
USGS	United States Geological Survey
WLRD	Water and Land Resources Division
WQ	Water Quality
WQI	Water Quality Index

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Introduction

Beginning in 2002, the King County Water and Land Resources Division (WLRD) has been conducting a baseline study to assess whether resident benthic macroinvertebrate communities accurately reflect the environmental conditions in the monitored watercourses, and thereby provide a practical tool for monitoring changes in aquatic ecosystem health. Our analysis of the WLRD's 2002 benthic macroinvertebrate data has focused on examining the effectiveness of the Benthic Index of Biotic Integrity (B-IBI) as a method of monitoring and characterizing the invertebrate communities of King County streams.

Data Sources

We used data collected from a total of 148 sites in 20 sub-basins in the Green-Duwamish River and Greater Lake Washington watersheds during July and August 2002. Our analysis included data from a total of 26 water quality (WQ) monitoring stations and 23 hydrological gauging stations. We also considered land-use data derived from WLRD's GIS land-use database to derive the percentage effective impervious area (%EIA) and land-use types upstream from each benthic macroinvertebrate sampling site.

B-IBI Scores

Mean sub-basin B-IBI scores in King County streams ranged from a high of 37.8 in the Issaquah sub-basin, to a low of 14.8 in the Duwamish sub-basin. Of the 20 sub-basins sampled, seven were ranked as having "fair" average B-IBI scores, three "fair-poor, seven "poor", and three "very poor". Seven of the sites within the Issaquah sub-basin had "good" B-IBI rankings, however the mean sub-basin B-IBI score was reduced to "fair" because of the presence of a single "poor" site. The B-IBI scores indicate that most of the watercourses in the Issaquah sub-basin are in relatively good biological condition, whereas most of the watercourses in the Duwamish and Black sub-basins are heavily impacted by human development.

B-IBI Scores and Other Indices

In general, there are significant correlations between a sample's B-IBI score and the number of invertebrate taxa present, the number of EPT taxa present, the sample's Shannon-Weiner Diversity Index (SWDI), and its Hilsenhoff Biotic Index (HBI). SWDI and HBI are alternative methods to B-IBI for measuring invertebrate community diversity.

B-IBI Scores and Function Feeding Groups

There is no apparent relationship between a sample's B-IBI score and the proportions of organisms in various functional feeding groups, and the mean proportions of organisms in the various functional feeding groups are generally consistent among sub-basins. Although the taxonomic composition and diversity of benthic macroinvertebrate communities vary widely among the sampled communities, the structure of all the communities, in terms of the proportion of organisms in each feeding group, is similar.

B-IBI and Land Use

In general, the B-IBI score of a given site is closely correlated with the land-use practices within the site's watershed, whether this is measured in terms of the percentage effective impervious area (%EIA), or the proportion of a watershed that is occupied by different types of development.

B-IBI increases as the amount of forest and scrub/shrub in a watershed increases, and decreases with the amount of developed land (i.e., bare ground/asphalt, bare rock/concrete, and high, medium, and low-intensity development). As the %EIA in a watershed increases, its B-IBI score decreases.

B-IBI and Water Quality

As mean base-flow conductivity, alkalinity, turbidity, total suspended solids (TSS), total phosphorus (P), total zinc (Zn), and total copper (Cu) in a stream increase, B-IBI scores decrease. However, these parameters are often significantly correlated with one another, which makes it difficult to infer a causal relationship between individual water quality variables and B-IBI score.

Water Quality and Land-Use

In light of the very strong correlations observed between site-level B-IBI scores and land-use parameters, we examined the relationship between water quality parameters and land-use. The most consistent correlations were observed between land-use and conductivity, and between land-use and alkalinity. As watersheds become increasingly urbanized, the conductivity and alkalinity of their watercourses increase.

B-IBI and Aquatic Habitat Variables

B-IBI scores were significantly positively correlated with all four of the habitat variables measured (i.e., dominant and subdominant substrate particle size, and left and right bank riparian tree density). B-IBI score increased with increasing substrate particle size, and increased with increasing riparian tree density.

B-IBI and Hydrology

The lower the stream velocity measured at a sampling site, the higher the site's B-IBI score. Conversely, the greater the discharge at a site, the higher its B-IBI score. Instantaneous flow (at the time of sampling) was observed to increase with increasing watershed area, and with increasing watershed urbanization. However, this was not true for stream discharge.

Conclusions

The B-IBI provides a useful tool for monitoring ecosystem health in King County streams, providing scores that closely parallel the degree of urbanization in the sampled watersheds.

The following responses are offered in response to the questions that this study was designed to address:

Question 1: *Do different sub-basins differ in terms of biological condition?* Of 148 watercourses sampled in King County, 60% had "poor" or "very poor" B-IBI scores, and the remaining 40% had scores ranging from "fair" to "good". The sub-basins in the best biological condition are Issaquah and Deep/Coal sub-basins, where watercourses generally have "good" or "fair" B-IBI scores. In contrast, all watercourses in the Black, Duwamish, and West Lake Washington sub-basins had "poor" or very poor" B-IBI scores. Other sub-basins have watercourses with B-IBI scores ranging from "very poor" to "good".

Question 2: *Do different land use patterns measured at the sub-basin level affect biological conditions differently within the watershed?* A strong degree of correlation was found between land-use patterns and B-IBI scores. Although it was not possible for us to determine precisely which urbanization-related hydrological or water quality parameters are causing invertebrate community integrity to decline with increasing urban development, B-IBI scores are significantly negatively correlated with conductivity, alkalinity, turbidity, and total suspended solids. B-IBI scores are also correlated with stream flow and discharge.

As 2002 was the first year of the benthic program, we were not able to address the questions: "*Is the biological condition improving (or declining) over time?*" and "*Is the trend significant?*" Upon completion of 2003 benthic data analyses, an initial evaluation of temporal trends will be possible, although it will probably require at least 5 years of data to adequately address this question, due to annual variability.

We recommend continued use of the B-IBI for monitoring King County streams, because it appears to provide the most useful information of the different indices tested.

1. INTRODUCTION

1.1 PROJECT OVERVIEW

King County Water and Land Resources Division (WLRD) is responsible for monitoring water quality and overall ecological health of stream systems within the County's jurisdiction. In addition to examining physical and chemical water quality variables, WLRD's monitoring program includes a benthic macroinvertebrate sampling component.

Using biological assemblages to evaluate the effects of anthropogenic activities on receiving environments offers several distinct advantages over approaches that rely solely on the measurement of physical or chemical parameters. The health of a stream's resident biological community is a reflection of the combined effects of water chemistry, sediment chemistry, physical habitat, hydrology, nutrient levels, and food availability. Therefore, biological monitoring should provide an integrated assessment of the receiving environment's long-term assimilation of disturbances, as opposed the one-time snapshot provided by some types of water quality monitoring. Programs designed to monitor changes in fish, periphyton and benthic macroinvertebrate communities in response to urban development, forestry, agriculture, or recreation are currently in place in various regions of the US, Canada, and Europe.

The interpretation of benthic macroinvertebrate community data can be considerably more complex than the interpretation of chemical or physical data. However, the handling of invertebrate taxonomic data can be simplified through the use of indices, which serve to distill a complex dataset into a simple numerical score based on the community's attributes (e.g., numbers and types of taxa, pollution tolerance). These scores can then be compared to qualitative values that correspond to known states of health (i.e., excellent, good, fair, poor, very poor) of the indicator community.

One widely used benthic invertebrate community index is the *Benthic Index of Biotic Integrity* (B-IBI), which was developed specifically for the Puget Sound lowlands. The B-IBI is calculated using a set of benthic community attributes or "metrics", which are sensitive to environmental changes (Karr and Chu, 1997; Karr, 1998). It is designed to facilitate comparison of results between sites and sampling dates. The overall goal of this report is to evaluate the usefulness of the B-IBI as a tool for monitoring the health of King County streams.

1.2 GOALS/PURPOSE OF REPORT

Our analysis of King County's 2002 benthic macroinvertebrate data was structured to address a series of questions set out by WLRD in their *Benthic Sampling and Analysis Plan* (SAP; King County, 2002a). These questions were:

1. Do different sub-basins within the Greater Lake Washington watershed differ in terms of biological condition?
2. Do different sub-basins within the Green-Duwamish watershed differ in terms of biological condition?
3. Is the biological condition improving (or declining) over time? Is the trend significant?
4. Do different land use patterns measured at the sub-basin level affect biological conditions differently within the watershed?

These questions summarize the overall goals of the SAP program, and recognize that answers may not possible until several years of data have been collected. To address Questions 1 and 2, we summarized the benthic macroinvertebrate data collected from sites in the Green-Duwamish and Greater Lake Washington watersheds, and used these data to calculate B-IBI scores for each site, along with other common indices of benthic macroinvertebrate community structure (i.e., functional feeding group, Hilsenhoff biotic index, Shannon-Weiner diversity index). We also used the B-IBI scores to rate the biological conditions (i.e., poor–excellent) within the different sub-basins of the Green-Duwamish and Greater Lake Washington watersheds.

As an additional line of evidence for biological condition, and to make use of the available monitoring data, we also used physical and chemical water quality data collected at invertebrate monitoring stations – or comparable sites – to determine if there were correlations between physico-chemical parameters (or indices) and B-IBI scores.

To begin addressing Question 3, we summarized the benthic macroinvertebrate data to establish a "baseline" against which future changes in habitat conditions (e.g., such as wastewater conveyance lines, roads, stormwater drainage, erosion, vegetation clearing, natural catastrophic events, etc.) in each sub-basin can be measured. Answering Question 3 will require several years of study, and is beyond the scope the current report.

To address Question 4, we used GIS land-use data collected by WRLD staff and compared each benthic station's upstream land-use patterns with its B-IBI score. When there were cases where the macroinvertebrate data indicated substantial habitat impairment in a particular sub-basin, we used available data concerning land-use, water quality, and hydrology in an attempt to investigate potential sources of this impairment.

1.3 BACKGROUND: INVERTEBRATE MONITORING IN KING COUNTY

Within King Country WLRD, monitoring of benthic macroinvertebrate communities takes place under two distinct programs, one wastewater-related, and the other surface water-related.

The wastewater-related benthic monitoring program was initiated in the mid-1970s. The primary objective was to monitor streams that were, or could potentially be, impacted by untreated wastewater, treated effluent, and the system of pipes and pumps that make up the wastewater collection and transfer system. This program continues today relatively unchanged and is part of a regional water quality monitoring program that includes lakes, mainstem rivers and streams.

In the mid-1990s "Basin Plans" were created for six King County watersheds: Lower Cedar River, Soos Creek, Bear Creek, Issaquah Creek, May Creek, and East Lake Sammamish. The goal of the *Basin Management Evaluation Program* (BMEP) macroinvertebrate monitoring program was to provide data that would allow assessment of the success of the Basin Plans and, when possible, to make specific recommendations for improved management. Macroinvertebrate samples have been collected in these basins since 1995.

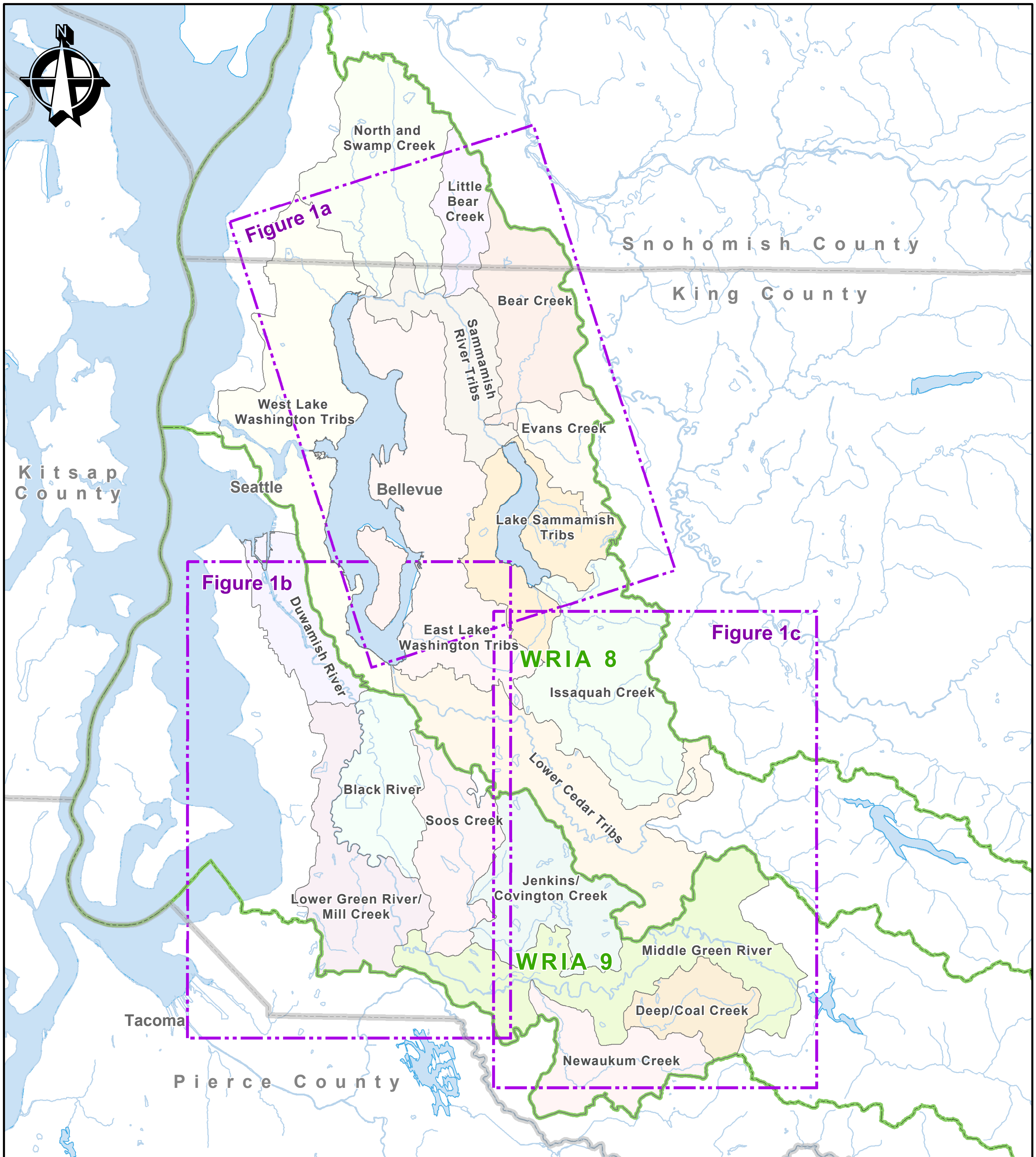
The wastewater and surface water programs were designed and implemented to address different, but related and complimentary, water quality issues. As part of a larger effort to consolidate WLRD's freshwater monitoring programs, a study was commissioned to combine the data generated by the two benthic macroinvertebrate monitoring programs, to allow for long-term trend detection on a larger scale than was previously possible. This report presents the data from the first year of the new program.

2. METHODS

2.1 STUDY AREA

The study area includes both the Green-Duwamish River watershed (Water Resource Inventory Area [WRIA] 9) and the Greater lake Washington watershed (WRIA 8). The Green-Duwamish watershed extends from the crest of the Cascade Mountains at the headwaters of the Green River, west to the mouth of the Duwamish River where the river empties into Elliott Bay at the City of Seattle. In the Green-Duwamish watershed, the following sub-basins were sampled: Black, Covington, Deep/Coal, Duwamish, Jenkins, Lower Green, Middle Green, Mill Creek, Newaukum, and Soos (Figure 1).

The Greater Lake Washington-Cedar River drainage encompasses the land area in which rainwater drains to the Sammamish River and out into Lake Washington. The watershed includes the following sampled sub-basins: Bear Creek, Cedar River, East Lake Washington, Evans Creek, Issaquah Creek, Lake Sammamish tributaries, Little Bear Creek, North/Swamp Creek, Sammamish River tributaries, and West Lake Washington (Figure 1).



LEGEND

- 1-100K Map Boundary
- WRIA Boundary
- Watershed Sub-basin Boundary (Color fills used for differentiation between adjacent watersheds)
- County Boundary
- Water Course
- Open Water

Projection: Lambert Conformal Conic

0 5 10 15 20 Miles

EVS environment consultants

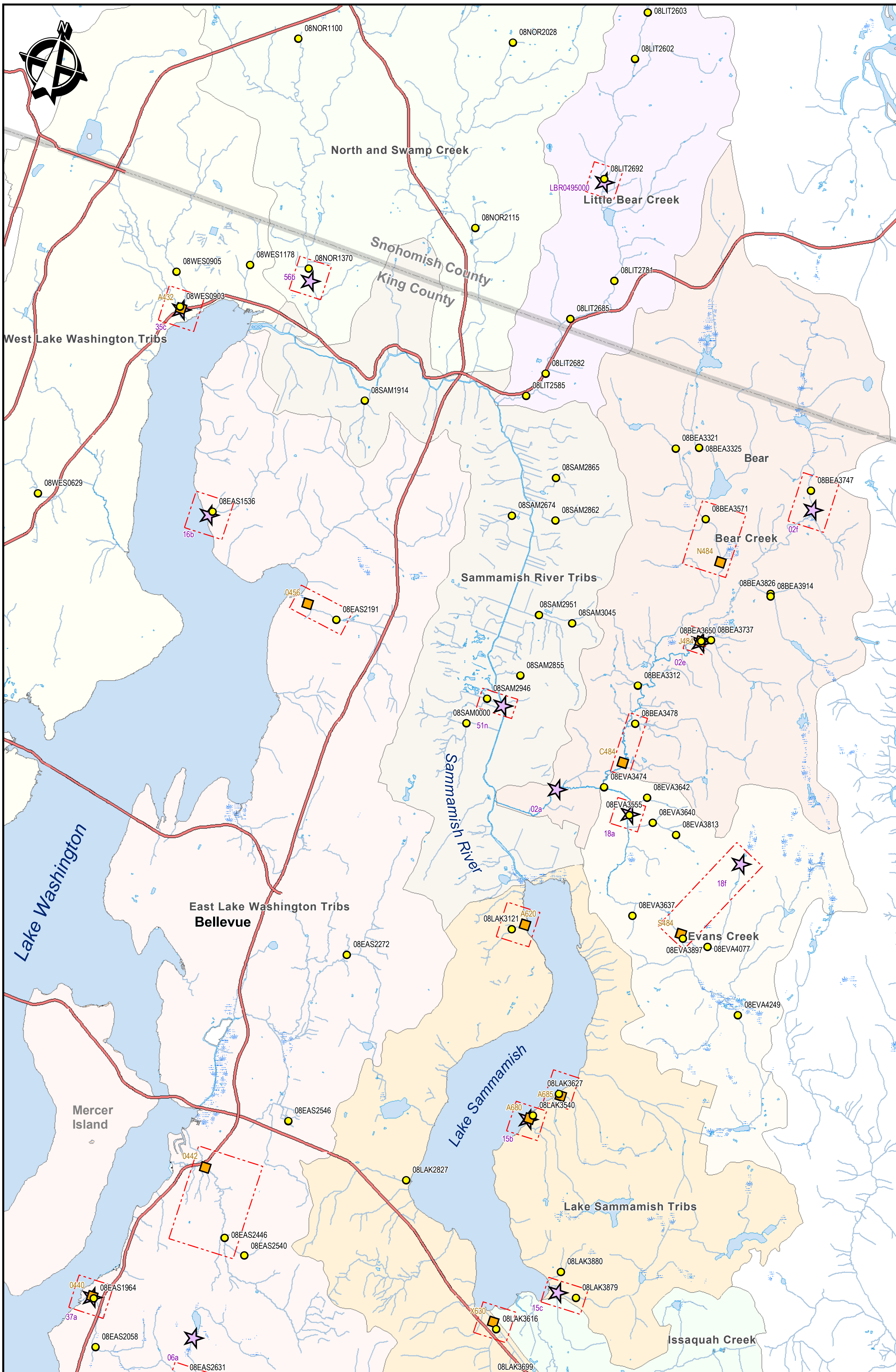
PROJECT: King County Water Quality Evaluation

LOCATION: King County, Washington

CLIENT: King County

TITLE: **2002 Study Area Overview**

DWG BY: GGC	CHK BY: PEM	PROJECT No.: 03-1116-01
SCALE: 1:440,000	DATE: 05/2004	**FIGURE 1**



LEGEND

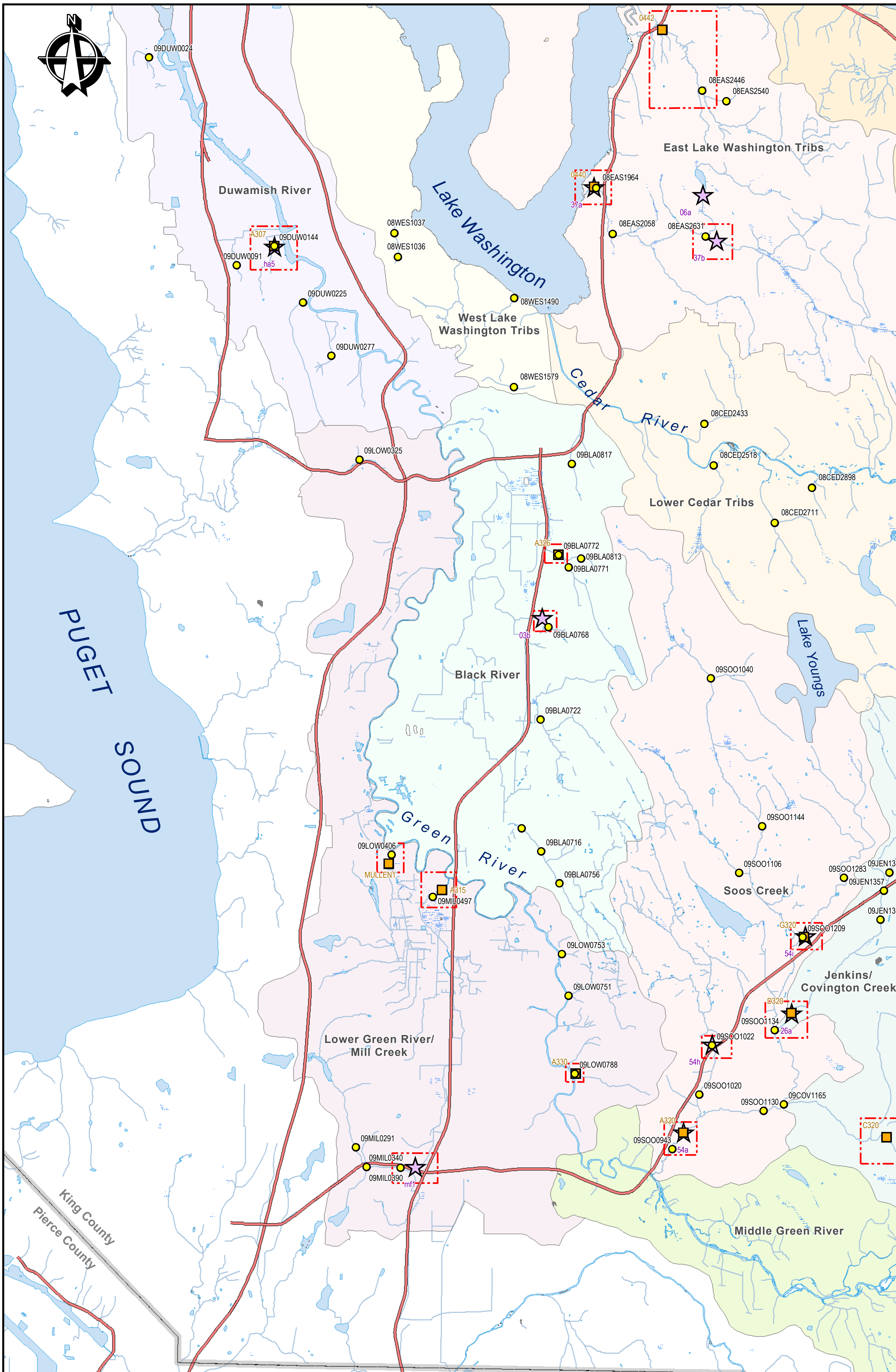
- Benthic Station
- Water Quality Station
- Hydrogauge Station
- Station Group Boundary
- Open water
- Wetland
- Water Course
- Watershed Sub-Basin Boundary (Color fills used for differentiation between adjacent watersheds)
- Major Highways
- County Boundary

Projection: Lambert Conformal Conic, NAD 83

0 1 2 3 4 5 Miles

EVS environment consultants

PROJECT: King County Water Quality Evaluation	
LOCATION: King County, Washington	CLIENT: King County
TITLE: **Benthic, Water quality and Hydrogauge Stations in Northern Section of 2002 Study Area**	
DWG BY: GGC	CHK BY: PEM
PROJECT No.: 03-1116-01	
SCALE: 1:100,000	DATE: 08/2004
FIGURE 1a	



LEGEND

- Benthic Station
- Water Quality Station
- Hydrogauge Station
- Station Group Boundary
- Water Course
- Open water
- Wetland
- Watershed Sub-basin Boundary (Color fills used for differentiation between adjacent watersheds)
- County Boundary
- Major Highways

Projection: Lambert Conformal Conic, NAD 83

0 1 2 3 4 5 Miles

EVS environment consultants

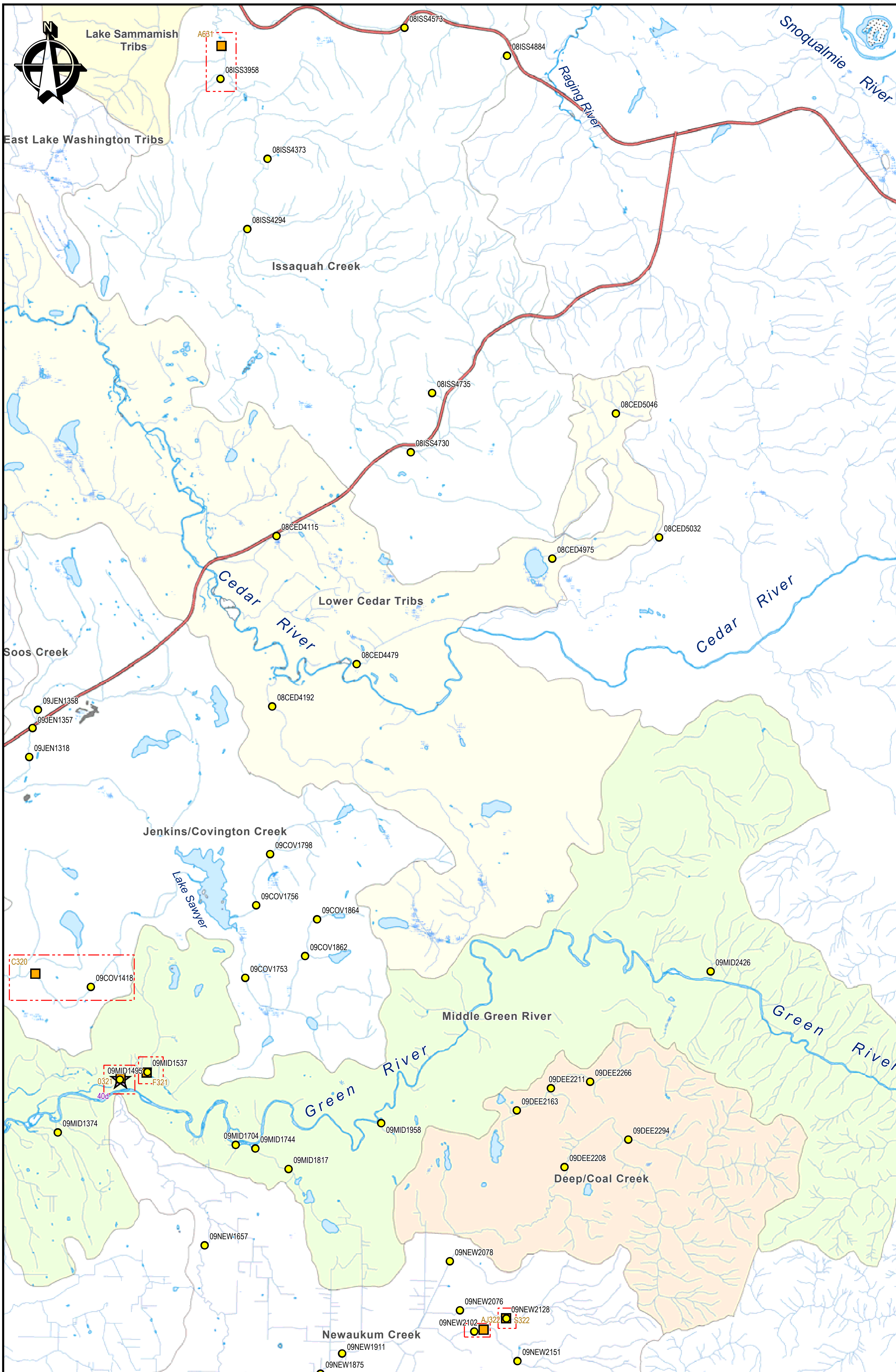
PROJECT: King County Water Quality Evaluation

LOCATION: King County, Washington

CLIENT: King County

TITLE: **Benthic, Water quality and Hydrogauge Stations in Southwestern Section of 2002 Study Area**

DWG BY: GGC	CHK BY: PEM	PROJECT No.: 03-1116-01
SCALE: 1:100,000	DATE: 07/2004	FIGURE 1b



LEGEND

- Macroinvertebrate Station
- Water Quality Station
- Hydrogauge Station
- Station Group Boundary
- Water Course
- Open water
- Wetland
- Watershed Sub-Basin Boundary (Color fills used for differentiation between adjacent watersheds)
- County Boundary
- Major Highways

Projection: Lambert Conformal Conic, NAD 83

0 1 2 3 4 5 Miles

EVS environment consultants

PROJECT:	King County Water Quality Evaluation
LOCATION: King County, Washington	CLIENT: King County
TITLE:	**Benthic, Water quality and Hydrogauge Stations in Southeastern Section of 2002 Study Area**
DWG BY: GGC / CHK BY: PEM	PROJECT No.: 03-1116-01
SCALE: 1:100,000 / DATE: 05/2004	**FIGURE 1c**

2.2 DATA SOURCES

2.2.1 Benthic Macroinvertebrate Data

Over the two-month period from July 30 to September 30, 2002, personnel from King County WLRD collected benthic macroinvertebrate data from a total of 148 sites in 20 sub-basins in the Green-Duwamish and Greater Lake Washington watersheds (Figure 1, Appendix A). Thirteen of these sites were sampled twice, resulting in macroinvertebrate data from 161 "sites" included in our analysis. Data from the thirteen duplicate sites were used as a qualitative check of sampling variability, but were not used in calculations of watershed mean values. Sample site selection protocols, benthic macroinvertebrate sampling procedures, sample processing, and identification of organisms followed the *Greater Lake Washington and Green-Duwamish River Watersheds Wadeable Freshwater Streams Benthic Macroinvertebrate Sampling and Analysis Plan* (King County, 2002a).

An important aspect of the sample site selection process was the incorporation of a randomized approach to reduce the potential for statistical bias. Using the County's Geographic Information System (GIS), a 0.33 square mile (85.47 ha) grid was digitally overlain on a map of each watershed, and a random number generator was used to select 30 sites per sub-basin from the total pool of potential sites. Closer inspection of the potential sites reduced the potential sites to 10 suitable sites per sub-basin. Using this method, a total of 148 sites were identified in the 20 sub-basins across the two watersheds. Lack of property access and/or suitable riffles resulted in fewer than 10 sites being sampled in some sub-basins (e.g., Jenkins, Mill).

Field invertebrate sampling involved collection of three replicate sub-samples from each site, then pooling the collected organisms into a single sample. This differs from Karr's (1998) prescribed macroinvertebrate sampling protocol, which specifies that each of three replicate sub-samples be processed separately. As a result, it was not possible for us to determine the taxonomic composition of each replicate sub-sample, nor was it possible to assess intra-site variability of B-IBI scores. Although this deviation from the "standard" protocol did not compromise the quality of our benthic macroinvertebrate data, it makes it difficult to compare the King County WLRD's data with data collected elsewhere using Karr's (1998) protocol.

All benthic macroinvertebrate samples were identified by Rhithron Associates of Missoula, Montana. A minimum of 500 organisms per sample were identified using appropriate sub-sampling techniques.

2.2.2 Physico-Chemical Data

Data from a total of 26 water quality (WQ) stations and 23 hydrological gauging stations were used in our analysis (Appendix A). Usually, the WQ and hydrological monitoring stations were not located at the same sites as the benthic sampling sites (Figure 1). The

WQ and hydrological monitoring stations were "matched" with benthic sampling sites into "station groups" (indicated as station group boundaries in Figures 1a to 1c) based on the following criteria:

- The proximity of WQ and hydrological monitoring stations to the benthic sampling station. Although a maximum acceptable distance between the physico-chemical monitoring stations and the benthic sampling stations was not explicitly stated, stations close together were most desirable. The distances from the benthic stations to the hydrogauge stations ranged from being at the same location (0 ft) to a maximum downstream distance of 10,950 ft (2.07 miles). The distances from the benthic stations to the WQ stations ranged from being the same location (0 ft) to a maximum downstream distance of 7,870 ft (1.49 miles).
- The WQ and/or hydrological monitoring stations were situated at locations with similar gradients to the benthic sampling stations.
- The WQ monitoring station selected was ideally one nearest the benthic sampling station that was not obviously influenced by potential point and non-point pollution sources (e.g., tributary inflows) between two stations.

2.2.2.1 Water Quality Data

Most of the WQ data were collected in the Green-Duwamish watershed as part of King County's ongoing ambient monitoring program, and were provided by King County (Henderson, *pers. comm*., 2004) and Herrera Environmental Consultants (Lenth, *pers. comm*., 2003). All mean data provided by King County were calculated as arithmetic means. The following water quality monitoring parameters were used in our analyses:

- Temperature (°C) – mean temperature at base-flow and at storm-flow;
- Dissolved oxygen (DO) (mg/L) – mean DO at base-flow;
- Conductivity (µmhos/cm) – mean conductivity at base-flow and at storm-flow;
- pH – mean pH at base-flow;
- Alkalinity (mg/L as $CaCO_3$) – mean alkalinity at base-flow and at storm-flow;
- Turbidity (NTU) – mean turbidity at base-flow and at storm-flow;
- Total Suspended Solids (TSS) (mg/L) – mean TSS at base-flow and at storm-flow;
- Dissolved Organic Carbon (DOC) (mg/L) – mean DOC at base-flow;
- Total Organic Carbon (TOC) (mg/L) – mean TOC at base-flow;
- Total phosphorus (P) – mean total P at base-flow and at storm-flow;
- Total zinc (Zn) – mean total Zn at base-flow and at storm-flow; and
- Total copper (Cu) – mean total Cu at base-flow and at storm-flow.

2.2.2.2 Hydrology Data

At each benthic sampling site, a series of water velocity measurements were made while invertebrate sampling was carried out. The average of these three values was then calculated and recorded. In addition, King County calculated GIS-derived measurements of upstream watershed area (in acres) for each benthic macroinvertebrate sampling site.

Discharge (Q) is a measure of the volume of water flowing through a stream channel cross-section per unit time, measured in cubic feet per second (cfs). Discharge data used in our analyses were collected as part of King County's gauging program, and were provided by King County (Henderson, *pers. comm*., 2004). The following types of discharge data were included in our analyses:

- Mean annual daily Q;
- Annual minimum daily Q;
- Annual maximum daily Q;
- Annual minimum instantaneous Q; and
- Annual maximum instantaneous Q.

From the raw data collected at each hydrogauge station, the mean, minimum and maximum daily Qs were calculated by King County staff for each day in the water year (October 2001 to September 2002). Mean annual daily Q was determined by taking the mean of all daily mean Qs for the water year. The minimum and maximum daily Qs were taken as the minimum or maximum value from the mean daily Qs for the entire water year. A slightly different approach yielded the annual minimum and maximum instantaneous daily Q values; annual minimum instantaneous Q was determined as the lowest minimum daily Q for the water year (as opposed to the lowest mean daily Q for the water year), and annual maximum instantaneous Q was the highest maximum daily Q for the water year (as opposed to the highest mean daily Q for the water year).

2.2.2.3 Land-Use Data

King County WLRD used its GIS land-use database, derived from the 1995 Landsat satellite image[1], to derive the percentage effective impervious area (%EIA) upstream from each benthic macroinvertebrate sampling site. Table 1 provides definitions of the EIA assumptions made by the County. In addition, they calculated the upstream surface area that was occupied by each of the following land-use types:

- Bare ground/asphalt,
- Bare rock/concrete,
- Developed - high intensity,

[1] see http://metrokc.gov/gis/sdc/raster/landcover/Landcover_Data.htm#1995Landcover

- Developed – medium intensity,
- Developed - low intensity,
- Forest,
- Scrub/shrub,
- Grass, and
- Open water.

These data were used to calculate the percentage of the area upstream from the sampling sites that was occupied by type of land-use (Table 2).

Table 1: Definition of EIA assumptions made for each land-use classification.

1995-classified Landsat image Grid Code	Grid Description	Aggregated Grid Code	Aggregated Grid Description	Assumed Percent EIA
1	Mixed Forest	5	Forest	0.5%
2	Deciduous	5	Forest	0.5%
3	Conifer - Early	5	Forest	0.5%
4	Conifer - Middle	5	Forest	0.5%
5	Conifer - Mature	5	Forest	0.5%
6	Recently Cleard	7	Scrub/Shrub	1.0%
7	Scrub/Shrub	7	Scrub/Shrub	1.0%
10	Grass - Brown	11	Grass	2.0%
11	Grass - Green	11	Grass	2.0%
12	Developed - Low Intensity	12	Developed - Low Intensity	4.0%
13	Developed - Medium Intensity	13	Developed - Medium Intensity	10.0%
14	Developed - High Intensity	14	Developed - High Intensity	25.0%
15	Bare Ground/Asphalt	15	Bare Ground/Asphalt	85.0%
16	Bare Rock/Concrete	16	Bare Rock/Concrete	85.0%
18	Open Water	18	Open Water	0.0%
20	Shadow	20	Shadow	0.0%

Table 2: Watershed land-use summary table for each benthic station.

SITE_ID	SiteAcres (total for site)	Bare Ground/Asphalt	Bare Rock/Concrete	Developed - High Intensity	Developed - Low Intensity	Developed - Medium Intensity	Forest	Grass	Open Water	Scrub/Shrub	Shadow	spring fed; surrounding area is forested
08BEA3312	347.0	1.27%		0.63%	36.39%	6.66%	30.90%	15.76%		8.39%		
08BEA3321	1142.4	2.40%	0.01%	0.74%	52.31%	6.47%	25.61%	4.76%	0.37%	7.33%		
08BEA3325	3375.7	2.33%	0.31%	1.02%	36.44%	6.03%	37.91%	6.74%	1.05%	8.15%	0.01%	
08BEA3478	1104.4	0.15%	0.03%	0.55%	30.30%	2.42%	48.83%	8.85%	0.08%	8.78%		
08BEA3571	6913.3	1.77%	0.16%	0.77%	41.87%	6.06%	34.70%	5.41%	1.34%	7.90%	0.00%	
08BEA3650	8860.0	0.50%	0.02%	0.33%	29.08%	3.68%	54.62%	3.50%	0.48%	7.79%	0.01%	
08BEA3737	982.8	0.19%	0.02%	0.17%	15.60%	1.11%	75.73%	2.20%	0.08%	4.90%		
08BEA3747	3163.8	0.39%	0.01%	0.32%	26.71%	2.28%	57.91%	2.51%	0.99%	8.87%		
08BEA3826	500.9	0.74%		0.19%	39.59%	7.46%	41.76%	2.18%	0.14%	7.94%		
08BEA3914	1457.9	0.61%	0.02%	0.38%	17.62%	3.60%	69.08%	1.54%	0.59%	6.52%	0.03%	
08CED2433	1044.3	8.72%	0.18%	1.17%	33.05%	23.61%	22.66%	5.09%		5.51%		
08CED2518	1198.4	5.17%	0.18%	1.38%	32.53%	23.32%	24.72%	7.08%		5.63%		
08CED2711	773.6	3.17%	0.22%	0.89%	29.61%	35.66%	16.50%	9.11%		4.85%		
08CED2898	141.2	0.29%		0.11%	17.72%	5.71%	64.27%	2.19%		9.71%		
08CED4115	1725.2	0.15%		0.35%	29.34%	2.22%	43.53%	6.64%	0.02%	17.74%		
08CED4192	9504.6	1.49%	0.01%	0.28%	12.79%	1.26%	61.48%	2.49%	0.68%	19.52%	0.00%	
08CED4479	4208.8	0.06%		0.17%	7.75%	0.86%	84.71%	0.81%	1.66%	3.90%	0.06%	
08CED4975	467.1				2.58%		96.86%			0.55%		
08CED5032	1124.4				1.83%		96.99%	0.63%		0.55%		
08CED5046	391.9				0.12%		99.88%					
08EAS1502	266.5	3.18%	0.25%	1.94%	48.45%	35.83%	5.65%	3.19%		1.52%		
08EAS1536	852.2	2.38%	0.04%	0.97%	36.47%	26.13%	28.44%	3.69%	0.00%	1.87%		
08EAS1964	9227.7	2.93%	0.09%	0.80%	24.56%	10.89%	48.47%	5.64%	0.37%	6.23%	0.00%	
08EAS2058	8893.5	2.84%	0.08%	0.80%	23.94%	10.52%	49.34%	5.75%	0.39%	6.35%	0.00%	
08EAS2191	1908.5	6.01%	0.42%	4.21%	44.41%	24.74%	14.46%	2.87%	0.18%	2.69%	0.01%	
08EAS2272	3472.2	10.09%	0.77%	6.05%	43.13%	18.43%	12.41%	5.12%	0.16%	3.84%		
08EAS2446	4137.4	2.76%	0.10%	0.90%	22.55%	17.02%	51.42%	2.90%		2.34%		
08EAS2540	174.7	0.44%		0.83%	44.07%	24.20%	27.11%	1.41%		1.93%		
08EAS2546	125.4	24.42%	1.97%	11.50%	28.81%	24.99%	3.92%	3.00%		1.40%		
08EAS2631	6975.2	1.64%	0.05%	0.65%	22.12%	6.44%	55.41%	6.07%	0.49%	7.12%	0.00%	
08EVA3474	9758.9	2.85%	0.09%	0.61%	30.94%	7.14%	44.81%	5.90%	0.14%	7.52%	0.00%	
08EVA3555	9289.1	2.38%	0.09%	0.54%	31.09%	7.27%	45.67%	5.43%	0.14%	7.38%	0.00%	
08EVA3637	93.0				32.12%	13.19%	52.42%	0.66%		1.61%		
08EVA3640	402.4	0.33%	0.04%	0.47%	40.98%	4.21%	31.81%	11.14%		11.02%		
08EVA3642	130.7	0.50%		0.80%	36.67%	2.67%	38.09%	10.42%		10.85%		
08EVA3813	199.7	0.28%		0.23%	46.57%	6.78%	30.44%	2.89%		12.81%		
08EVA3897	7085.8	1.01%	0.01%	0.36%	30.54%	7.19%	49.77%	3.71%	0.13%	7.28%	0.00%	
08EVA4077	1389.8	0.33%	0.01%	0.33%	35.23%	4.07%	50.10%	3.51%		6.43%		
08EVA4249	1413.7	1.70%	0.02%	0.64%	26.81%	4.76%	52.99%	4.60%	0.44%	8.03%	0.01%	
08ISS3877	32054.0	1.16%	0.03%	0.24%	13.31%	1.99%	73.79%	2.97%	0.11%	6.38%	0.02%	
08ISS3958	364.4				9.03%	0.61%	88.38%	0.72%		1.25%		
08ISS3962	31831.1	1.06%	0.03%	0.22%	13.22%	1.80%	74.22%	2.92%	0.11%	6.40%	0.02%	
08ISS4294	3067.5	0.12%		0.06%	10.79%	0.39%	85.50%	0.27%		2.86%		
08ISS4373	931.3			0.00%	3.64%	0.01%	93.91%	0.36%	0.63%	1.05%	0.40%	
08ISS4573	811.6	0.02%		0.08%	2.22%	0.28%	96.03%	0.02%		1.35%		
08ISS4724	3601.1	0.13%		0.14%	7.50%	0.43%	83.72%	1.95%	0.04%	6.09%		
08ISS4730	3758.6	0.51%		0.03%	4.18%	0.28%	90.49%	0.55%	0.01%	3.93%	0.00%	
08ISS4735												SPRING FED
08ISS4748	3763.2	0.90%	0.04%	0.09%	6.33%	1.68%	84.83%	1.11%		5.02%		
08ISS4884	513.8		0.06%	0.12%	3.02%	0.01%	88.87%	0.03%		7.89%		

Table 2 - continued i:

SITE_ID	SiteAcres (total for site)	Bare Ground/Asphalt	Bare Rock/Concrete	Developed - High Intensity	Developed - Low Intensity	Developed - Medium Intensity	Forest	Grass	Open Water	Scrub/Shrub	Shadow	spring fed; surrounding area is forested
08LAK2827	1135.6	5.38%	0.10%	2.22%	50.05%	27.53%	10.98%	1.33%	0.03%	2.39%		
08LAK3121	402.1	2.25%	0.18%	0.79%	44.50%	39.50%	9.95%	1.55%		1.27%		
08LAK3540	1219.9	1.31%	0.05%	1.02%	39.84%	5.36%	32.62%	5.76%	5.60%	8.44%		
08LAK3609	825.6	0.57%		0.09%	7.36%	0.56%	89.42%	0.28%	0.02%	1.69%		
08LAK3616	2972.0	2.24%	0.02%	0.22%	8.86%	2.59%	81.52%	2.40%	0.01%	2.16%		
08LAK3627	494.5	0.43%		0.20%	39.71%	3.20%	38.80%	6.09%		11.58%		
08LAK3628	1829.0	2.26%	0.55%	0.80%	37.89%	7.13%	38.25%	5.23%	0.04%	7.85%		
08LAK3699	2276.7	1.00%	0.01%	0.15%	9.65%	1.53%	83.19%	2.00%	0.01%	2.46%		
08LAK3879	3594.2	3.79%	0.15%	0.73%	30.49%	11.60%	38.12%	5.71%	1.62%	7.76%	0.02%	
08LAK3880	305.8	1.48%	0.05%	0.10%	44.58%	8.72%	37.62%	1.84%		5.61%		
08LIT2488	9602.4	6.02%	0.44%	1.58%	37.03%	8.91%	32.47%	5.94%	0.01%	7.61%	0.00%	
08LIT2585	9419.2	5.63%	0.41%	1.53%	37.34%	8.47%	33.01%	5.91%	0.01%	7.68%	0.00%	
08LIT2602	1125.5	13.60%	0.30%	1.33%	27.55%	11.07%	28.06%	7.90%		10.18%		
08LIT2603	636.1	20.38%	0.29%	1.55%	23.73%	15.86%	25.15%	6.18%		6.85%		
08LIT2682	9046.8	5.42%	0.37%	1.37%	37.29%	7.82%	33.83%	6.02%	0.01%	7.86%	0.00%	
08LIT2685	7928.4	4.83%	0.16%	0.93%	37.38%	7.17%	35.08%	6.09%	0.00%	8.35%	0.00%	
08LIT2692	3733.6	4.63%	0.12%	0.69%	34.52%	6.46%	36.59%	6.97%	0.00%	10.01%	0.01%	
08LIT2781	7322.3	3.84%	0.12%	0.73%	38.11%	6.55%	35.90%	6.19%	0.00%	8.56%	0.00%	
08LIT2876	609.2	2.37%	0.05%	0.51%	37.49%	4.90%	41.25%	7.36%		6.06%		
08NOR1100	381.5	31.81%	1.74%	14.16%	12.91%	24.67%	9.54%	3.53%		1.64%		
08NOR1362	13587.4	11.25%	0.86%	4.89%	31.04%	24.78%	18.12%	5.69%	0.47%	2.90%		
08NOR1370	14761.5	10.72%	0.84%	4.63%	31.48%	25.03%	18.39%	5.60%	0.44%	2.86%		
08NOR1750	3997.0	12.78%	0.56%	4.51%	28.52%	29.46%	18.73%	3.14%	0.00%	2.30%		
08NOR1756	1964.2	20.19%	0.91%	6.75%	22.68%	38.71%	7.10%	2.93%	0.01%	0.74%		
08NOR2028	776.3	4.43%	0.08%	0.94%	34.67%	45.54%	7.53%	3.80%	0.02%	3.00%		
08NOR2115	131.3	19.68%	1.53%	4.98%	27.20%	13.73%	21.60%	6.03%		5.26%		
08NOR2306	16872.3	7.54%	0.37%	2.61%	34.46%	22.33%	19.75%	6.93%	0.59%	5.44%	0.00%	
08NOR2316	918.7	4.51%	0.12%	1.04%	36.15%	7.86%	23.30%	15.99%		11.03%		
08SAM0000	1080.8	5.57%	1.10%	3.87%	46.19%	29.69%	6.52%	3.73%	0.57%	2.77%		
08SAM1914	455.3	6.25%	0.37%	1.24%	22.24%	16.81%	43.67%	5.80%		3.61%		
08SAM2674	143.2	2.10%	0.11%	0.11%	27.02%	16.57%	27.50%	21.07%	0.22%	5.32%		
08SAM2855	99.6	1.86%		1.24%	31.71%	50.20%	5.92%	6.05%		3.01%		
08SAM2862	606.6	0.48%	0.13%	0.57%	54.28%	6.87%	15.39%	13.68%		8.61%		
08SAM2865	168.7			0.09%	52.84%	2.25%	33.71%	3.52%		7.59%		
08SAM2946	141.5	5.97%		1.01%	38.45%	11.79%	22.35%	17.28%		3.16%		
08SAM2951	1318.4	1.55%	0.27%	0.70%	48.20%	8.48%	21.77%	12.73%		6.31%		
08SAM3045	100.7				69.08%	3.65%	21.32%	1.47%		4.49%		
08SAM3047	294.1	0.21%		0.26%	58.57%	4.00%	17.44%	11.38%		8.14%		
08SNC0001	3048.4	15.23%	1.11%	8.00%	27.49%	34.99%	9.01%	2.84%	0.04%	1.29%		
08WES0622												SPRING FED
08WES0629	1349.5	19.48%	0.61%	7.07%	25.30%	42.16%	2.86%	2.15%		0.35%		
08WES0903	5295.8	12.36%	0.71%	5.86%	33.59%	34.82%	5.86%	3.12%	1.72%	1.95%		
08WES0905	2661.3	3.40%	0.23%	1.61%	44.20%	34.07%	11.39%	2.89%	0.13%	2.09%		
08WES1036	583.9	5.06%	0.05%	1.96%	26.38%	54.93%	5.89%	4.99%		0.74%		
08WES1037	583.9	5.06%	0.05%	1.96%	26.38%	54.93%	5.89%	4.99%		0.74%		
08WES1178	800.1	1.92%	0.02%	1.26%	42.49%	37.68%	9.73%	4.25%	0.58%	2.08%		
08WES1304	720.5	4.24%	0.04%	2.25%	23.83%	51.10%	12.69%	5.12%	0.00%	0.72%		
08WES1490	125.1	1.41%	0.12%	2.86%	25.86%	55.31%	12.21%	1.85%		0.37%		
08WES1579	247.1	2.77%	0.19%	2.55%	37.88%	36.69%	5.51%	13.53%		0.88%		

Table 2 - continued ii:

SITE_ID	SiteAcres (total for site)	Bare Ground/Asphalt	Bare Rock/Concrete	Developed - High Intensity	Developed - Low Intensity	Developed - Medium Intensity	Forest	Grass	Open Water	Scrub/Shrub	Shadow	spring fed; surrounding area is forested
09Bla0650	14988.0	18.78%	1.73%	10.28%	24.09%	25.27%	8.37%	8.75%	0.07%	2.64%		
09Bla0675	1605.0	12.11%	0.76%	4.39%	33.93%	26.68%	11.75%	7.32%		3.06%		
09Bla0716	1605.0	12.11%	0.76%	4.39%	33.93%	26.68%	11.75%	7.32%		3.06%		
09Bla0722	1831.3	9.12%	0.12%	2.62%	32.52%	33.44%	7.99%	10.69%		3.50%		
09Bla0756	939.0	14.14%	0.69%	4.99%	33.51%	21.79%	13.20%	8.28%		3.40%		
09Bla0768	847.8	5.18%	0.53%	1.53%	30.67%	28.90%	22.89%	7.31%		2.99%		
09Bla0771	776.9	7.72%	0.10%	2.11%	33.18%	22.15%	18.03%	9.46%	0.02%	7.24%		
09Bla0772	1142.4	9.06%	0.09%	3.73%	31.51%	27.99%	13.47%	8.38%	0.01%	5.75%		
09BLA0813	365.5	11.90%	0.08%	7.17%	27.97%	40.42%	3.77%	6.10%		2.58%		
09Bla0817	1009.9	10.86%	0.29%	4.99%	32.17%	33.85%	10.87%	4.33%		2.65%		
09Cov1165	13891.8	2.92%	0.14%	0.89%	23.39%	4.51%	45.01%	4.98%	2.41%	15.75%	0.01%	
09Cov1418	10684.2	3.36%	0.16%	1.03%	18.45%	3.86%	49.60%	4.59%	2.62%	16.33%	0.01%	
09Cov1753	4258.6	5.49%	0.20%	1.53%	13.68%	4.17%	57.30%	4.02%	0.71%	12.87%	0.03%	
09Cov1756	2530.9	0.80%	0.33%	0.42%	10.85%	1.10%	62.46%	4.27%	0.67%	19.09%		
09Cov1798	1967.6	0.98%	0.42%	0.54%	9.23%	0.53%	66.50%	5.01%	0.86%	15.92%		
09Cov1862	1537.7	11.37%	0.51%	3.51%	19.11%	5.82%	40.25%	5.07%	0.60%	13.75%		
09Cov1864	1537.7	11.37%	0.51%	3.51%	19.11%	5.82%	40.25%	5.07%	0.60%	13.75%		
09Dee2163	2567.3	0.07%	0.01%	0.17%	10.67%	0.60%	71.60%	2.22%	1.49%	13.16%	0.02%	
09Dee2208	9039.4	0.11%	0.02%	0.43%	10.12%	0.42%	58.61%	4.80%	0.25%	24.90%	0.34%	
09Dee2211	2567.3	0.07%	0.01%	0.17%	10.67%	0.60%	71.60%	2.22%	1.49%	13.16%	0.02%	
09Dee2266	2567.3	0.07%	0.01%	0.17%	10.67%	0.60%	71.60%	2.22%	1.49%	13.16%	0.02%	
09Dee2294	9039.4	0.11%	0.02%	0.43%	10.12%	0.42%	58.61%	4.80%	0.25%	24.90%	0.34%	
09Duw0024	170.7	0.81%		0.72%	20.70%	24.18%	40.88%	10.90%		1.81%		
09Duw0091	988.2	12.76%	0.94%	4.53%	27.65%	41.44%	4.70%	7.20%		0.78%		
09Duw0144	517.0	6.93%	0.36%	2.26%	30.75%	33.05%	7.64%	17.05%	0.04%	1.91%		
09Duw0225	630.0	2.74%		1.17%	31.62%	53.61%	3.21%	6.21%	0.01%	1.43%		
09Duw0277	111.4	7.54%		2.32%	24.55%	37.71%	22.07%	5.26%		0.55%		
09Jen1318	5159.4	3.02%	0.09%	0.93%	30.05%	10.62%	35.79%	5.91%	0.84%	12.73%	0.03%	
09Jen1357	4516.6	2.81%	0.05%	0.87%	29.67%	7.45%	39.34%	5.77%	0.96%	13.04%	0.03%	
09Jen1358	2771.4	3.99%	0.08%	1.00%	29.88%	9.22%	38.10%	4.38%	0.17%	13.18%		
09Low0325	3627.9	19.10%	1.20%	10.66%	21.31%	31.76%	8.16%	6.45%	0.34%	1.02%		
09Low0406	3543.4	6.61%	0.33%	1.86%	27.16%	26.57%	18.87%	14.65%	0.96%	2.97%	0.01%	
09Low0751	991.0	1.28%	0.08%	1.09%	36.29%	7.21%	21.46%	17.93%		14.65%		
09Low0753	453.0	0.27%		0.17%	25.18%	3.15%	57.02%	8.98%	0.00%	5.24%		
09Low0788	537.7	6.51%	0.03%	0.83%	35.56%	20.12%	24.48%	6.84%		5.63%		
09Mid1374	851.9	0.28%		0.44%	19.00%	1.29%	26.81%	26.86%		25.32%		
09Mid1495	1455.0	0.43%	0.01%	0.20%	16.39%	2.12%	56.65%	5.86%	1.34%	16.95%	0.05%	
09Mid1537	1455.0	0.43%	0.01%	0.20%	16.39%	2.12%	56.65%	5.86%	1.34%	16.95%	0.05%	
09Mid1704	44219.4	0.32%	0.02%	0.37%	9.70%	0.52%	66.42%	3.68%	1.25%	17.56%	0.16%	
09Mid1744	44219.4	0.32%	0.02%	0.37%	9.70%	0.52%	66.42%	3.68%	1.25%	17.56%	0.16%	
09Mid1817	44219.4	0.32%	0.02%	0.37%	9.70%	0.52%	66.42%	3.68%	1.25%	17.56%	0.16%	
09Mid1958	44219.4	0.32%	0.02%	0.37%	9.70%	0.52%	66.42%	3.68%	1.25%	17.56%	0.16%	
09Mid2426	578.7	0.08%		0.27%	7.45%	0.07%	86.12%	0.37%	0.05%	4.78%	0.80%	
09Mil0291	2391.2	1.87%	0.03%	0.96%	38.95%	24.31%	23.42%	4.45%	1.35%	4.65%	0.01%	
09Mil0340	2391.2	1.87%	0.03%	0.96%	38.95%	24.31%	23.42%	4.45%	1.35%	4.65%	0.01%	
09Mil0390	2391.2	1.87%	0.03%	0.96%	38.95%	24.31%	23.42%	4.45%	1.35%	4.65%	0.01%	
09Mil0497	7824.5	13.77%	1.33%	5.29%	26.32%	19.62%	14.27%	15.27%	0.45%	3.68%	0.00%	

Table 2 - continued iii:

SITE_ID	SiteAcres (total for site)	Bare Ground/Asphalt	Bare Rock/Concrete	Developed - High Intensity	Developed - Low Intensity	Developed - Medium Intensity	Forest	Grass	Open Water	Scrub/Shrub	Shadow	spring fed; surrounding area is forested
09New1657	17304.4	1.11%	0.15%	0.73%	18.73%	4.25%	28.98%	26.72%	0.02%	19.28%	0.02%	
09New1875	8825.1	1.51%	0.15%	0.68%	15.82%	3.14%	38.85%	20.74%	0.04%	19.02%	0.03%	
09New1911	7989.2	1.53%	0.16%	0.62%	15.03%	2.89%	41.60%	18.83%	0.04%	19.27%	0.03%	
09New2076	1678.8	0.14%	0.04%	0.13%	10.31%	0.37%	64.50%	6.31%	0.02%	18.12%	0.07%	
09New2078	1290.7	0.38%	0.08%	0.34%	18.74%	0.91%	37.56%	24.83%		17.16%		
09New2102	1245.0	0.01%		0.15%	8.39%	0.16%	67.70%	5.80%		17.69%	0.10%	
09New2128	1312.2	0.01%	0.05%	0.15%	6.13%	0.07%	75.71%	1.44%	0.02%	16.34%	0.08%	
09New2151	892.8				5.14%	0.10%	77.95%	1.51%		15.20%	0.10%	
09Soo0943	42550.6	3.37%	0.13%	0.98%	28.77%	11.64%	32.99%	7.54%	1.47%	13.11%	0.01%	
09Soo1020	3508.2	3.81%	0.19%	1.27%	32.94%	18.93%	20.54%	13.26%	0.00%	9.07%		
09Soo1022	3508.2	3.81%	0.19%	1.27%	32.94%	18.93%	20.54%	13.26%	0.00%	9.07%		
09Soo1040	3549.9	2.30%	0.14%	1.19%	29.56%	21.89%	33.20%	6.02%	0.18%	5.51%		
09Soo1106	1613.5	4.87%	0.05%	0.66%	30.75%	36.05%	10.81%	12.20%	0.01%	4.60%		
09Soo1130	38038.6	3.31%	0.12%	0.93%	28.55%	11.07%	34.18%	7.09%	1.64%	13.10%	0.01%	
09Soo1134	22206.4	3.56%	0.12%	1.01%	31.84%	15.58%	27.14%	8.38%	1.30%	11.06%	0.01%	
09Soo1144	4823.5	1.97%	0.11%	1.02%	29.39%	18.05%	33.12%	8.54%	0.16%	7.63%		
09Soo1209	2367.1	2.45%	0.12%	0.88%	30.82%	8.24%	31.78%	11.34%	0.11%	14.27%		
09Soo1283	1841.1	0.79%	0.08%	0.48%	29.08%	4.65%	38.28%	11.56%	0.14%	14.94%		

2.2.2.4 Habitat Data

Descriptive, semi-quantitative habitat data were collected by King County WLRD field crews at most of the benthic macroinvertebrate sampling sites. Because these data were recorded in categories representing a range of values, they were converted to rank values for the purposes of our analyses. Habitat variable indexing is summarized in Table 3.

Table 3: Summary of rank values assigned to habitat variable categories.

SUBSTRATE SIZE CLASS (DOMINANT AND SUBDOMINANT)	RIPARIAN TREE DENSITY (RIGHT AND LEFT BANK)
1 = 0 mm	0 = no trees
2 = <2 mm	1 = <33% treed
3 = 2-8 mm	2 = >33% treed
4 = 8.1-64 mm	
5 = 64.1-128 mm	
6 = 128.1-256 mm	
7 = bedrock	

2.3 CALCULATION OF BENTHIC COMMUNITY INDICES

2.3.1 B-IBI

2.3.1.1 Overview

The B-IBI is a multi-metric approach that utilizes information concerning the abundance and composition of a stream's benthic macroinvertebrate community to assess the overall biological integrity of the stream ecosystem. In this context, "biological integrity" is defined as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitat of the region" (Karr and Dudley, 1981).

B-IBI scores can be calculated using either a 5-metric approach, wherein organisms are identified only to the family/order level[2], or a 10-metric approach, in which organisms are identified to the genus or species/family-level. In general, the 10-metric B-IBI is judged to provide a more accurate reflection of impact levels than the 5-metric B-IBI (Karr and Dudley, 1981), because it provides more detailed information about the composition of the invertebrate community.

For the purposes of our analyses, the species/family-level 10-metric B-IBI scoring methodology was used, primarily because Rhithron had identified most of the aquatic insects to the species level. Exceptions were certain caddisfly larvae (Rhyacophilidae; identified to subgroup); midge larvae (Chironomidae; identified to family); and non-insect invertebrates (identified to order or family).

To obtain a 10-metric B-IBI score, it is necessary to calculate and sum the ten metrics that describe individual key attributes (Appendix B) of the benthic macroinvertebrate community.

Average Metrics

Taxa Richness and Composition

- **Taxonomic richness** is the total number of distinct taxa identified in each sample.
- **Ephemeroptera taxonomic richness** is the total number of distinct taxa in the order Ephemeroptera (mayfly nymphs) identified in each sample. **Plecoptera** (stonefly nymph) **taxonomic richness** and **Trichoptera** (caddisfly larvae) **taxonomic richness** are two additional metrics included in the B-IBI score, and

[2] Taxonomic classification is hierarchical. For example, human beings belong to the kingdom Animalia, phylum Chordata, class Mammalia, order Primates, family Hominidae, genus *Homo*, and species *Homo sapiens*.

are calculated in the same way. Collectively, the taxonomic richness of these three taxa are referred to as **EPT taxonomic richness**.

Pollution Tolerance

- **Percent tolerant individuals** refers to the total number of pollution-tolerant individuals counted in each sample, divided by the total number of individuals counted in the sample *that had pollution tolerance assigned*, multiplied by 100.

  Pollution tolerance was assessed using the Community Tolerance Index (CTI) created by Wisseman (2002). This differs from the original (SalmonWeb[3] site) B-IBI metric scoring system, which uses the Hilsenhoff Biotic Index (HBI; see Section 2.3.3) values to rank the pollution tolerance invertebrate taxa. In 1998, Wisseman compiled the SalmonWeb HBI pollution-tolerance values using Hilsenhoff's (1998) data concerning the tolerances of invertebrate taxa to nutrient enrichment. According to Wisseman (2002), the HBI pollution tolerance values were subjectively derived, and primarily based on nutrient enrichment tolerance found by Hilsenhoff in the Midwest. Because the HBI is based on taxa from the Midwest, the tolerance scaling does not incorporate the full spectrum of habitat types and fauna encompassed in montane western North America. The CTI pollution-tolerance values therefore provide a more comprehensive evaluation of the effects of urban pollution, and better reflect habitat types and taxa found in the Pacific Northwest.

  In the CTI method, tolerance is generally defined by primary and secondary factors; primary factors are sensitivity to warm water and low levels of dissolved oxygen, whereas secondary factors include sensitivity to fouling of surfaces with filamentous algae or bacteria; sensitivity to siltation; sensitivity to disturbance (whether physical disturbance of substrates or chemical disturbance from toxins); and sensitivity to nutrient enrichment, (which is auto-correlated with dissolved oxygen and fouling). Taxa assigned tolerance values from 0-3 are considered intolerant, and those assigned values from 7-10 are considered tolerant. Taxa with intermediate values from 4-6 were not included in our analysis.

  Not all taxa found in King County are classified under the CTI system (nor are all classified by the HBI system). To account for this, only the taxa for which CTI pollution tolerance values were available were included when we calculated the "Percent Tolerant Individuals" metric. The use of only a subset of pollution-tolerance-classified taxa, when calculating percent tolerant individuals, is not specifically stated in the B-IBI protocol. However, if non-classified individuals are left in equations, it has the effect of creating a false increase in the number of intolerant taxa present, because if a taxon is not considered "tolerant", by default it is classified "intolerant", and the community appears to have a smaller proportion of pollution-tolerant individuals, and therefore lower B-IBI score. By removing these false intolerant species, we effectively eliminate false intolerant

[3] http://www.salmonweb.org

individuals and provide a more representative and more accurate measure of the proportion of tolerant individuals in a sample.

Feeding Ecology

- **Number of clinger taxa** refers to a particular behavior or habit exhibited by the invertebrate taxa, and describes where in the aquatic habitat the organism is mainly found, and conditions that it is adapted to (Merritt and Cummins, 1996). To remain as consistent as possible with the B-IBI protocol, the clinger databases of Wisseman (1998, as compiled by Ms. Leska Fore), and Barbour *et al*. (1999) were used to identify clinger taxa.
- **Percent predator individuals** refers to the total number of individuals in a sample belonging to the predator functional feeding group (as defined in Merritt and Cummins, 1996), divided by the total number of individuals in that sample and multiplied by 100. The predator database of Wisseman (1998, as compiled by Ms. Fore), and the Barbour *et al*. (1999) databases were used to identify predator taxa.

Population Attributes

- **Percent dominance** was calculated as the sum of individuals in the three most abundant taxa in the sample, divided by the total number of individuals in the sample and multiplied by 100.

Cumulative Metrics

- The **number of long-lived taxa** is the number of distinct taxa that have a life-cycle length exceeding one year (Wisseman, 2002). Wisseman's 2002 database, as opposed to his 1998 database, was used for categorizing organisms as being long-lived, because Wisseman considers the quality of the 2002 system to be much better than that of the 1998 system (Wisseman, *pers. comm*., 2003). Our definition of "long-lived" differs from that of Karr and Chu (1997) − which appears on the SalmonWeb site − wherein long-lived taxa are defined as those living at least two to three years in the immature state.
- The **number of intolerant taxa** is the number of distinct taxa considered pollution-intolerant, using the CTI (Wisseman, 2002).

2.3.1.2 Application of the B-IBI to the King County Dataset

To be used effectively, the B-IBI must first be calibrated for a region's streams. This usually involves sampling a range of stream types that represent a cross-section of the impact conditions in the region (e.g., from watersheds in "good" biological condition, to watersheds in "poor" biological condition). Calibration of the B-IBI for streams in the Puget Sound Lowlands was previously completed by Kleidl (1995).

We first compiled the four separate taxonomic datasets provided to us by King County WLRD (i.e., Green watershed, Greater Lake Washington watershed, five additional sites

[09MIL0497, 08LAK3616, 08LAK3540, 08LAK3627, 09SOO1209], and one additional site [08LAK3699]), to create a master list of all benthic macroinvertebrate taxa found in King County. Although King County provided the data in four separate source files, all sampling was completed under the same program. After all duplicate taxa were removed, attribute data were added to the spreadsheet from Wisseman (2002), Wisseman (1998), and Barbour *et al.* (1999). Duplicates were common, as all four data/sets contained many of the same taxa (Appendix D).

2.3.1.3 B-IBI Calculations For Each Station

Once the master taxa list was compiled and all four categories of attributes (i.e., taxa richness and composition, pollution tolerance, feeding ecology, population attribute) assigned, the taxa were sorted phylogenetically and the organism counts from each benthic macroinvertebrate collection station were added (Appendix E).

At this stage it was necessary to determine the numbers of distinct taxa present at each sampling station. An artifact of benthic taxonomy known as “phantom” taxa occurs when taxonomists are only able to identify some damaged or immature specimens to a taxonomic level (e.g., family) that is higher than for other members of that family (e.g., genus or species). When counting the number of taxa present in a sample, a false or phantom taxon will be enumerated if, within a given family, there are counts for specimens identified only to family in addition to specimens identified further to genus or species.

For immature or damaged specimens identified to the family-level, we determined if there were genera or species within that family. If genus- or species-level specimens were present in the sample, the family-identified specimen was not included in the count of total number of taxa. However, if there were no genus- or species-level specimens present, the family-level specimen was included in the count.

Detailed descriptions on our compilation of benthic attribute sources and calculation of B-IBI scores is provided in Appendix B.

2.3.1.4 QA/QC for B-IBI Scores, WQ and Habitat Data

Because data were transferred among several different spreadsheets, and because numerous calculations were required in order to determine B-IBI scores, an independent biologist completed a QA/QC check to ensure that the data in the various spreadsheets were consistent with the original data files. In all, a QA/QC was performed on 10% of all sections of the dataset (including original taxonomy count sheets from Rhithron, attributes used to calculate B-IBI scores, spreadsheet cells that calculated B-IBI scores, water quality parameters, flow, land-use data, and habitat data). If >10% error was found on any given section, a full check of the data for that entire section was performed.

2.3.2 Functional Feeding Group Analysis

The functional feeding group (FFG) approach is an alternative to using trophic levels (e.g., herbivore, detritivore, carnivore) to characterize food web relationships in aquatic systems. In temperate regions, much of the organic material processed in stream systems is of terrestrial origin; the FFG approach classifies organisms, particularly insects, according to their role in the processing of this material. Several factors are considered in assigning an organism to a FFG: the origin and size of the food items ingested (plant or animal, coarse or fine), the general location from which the food is taken (from substrates, or from the water column), the mechanisms of food acquisition (behavioral or morphological adaptations), and the organism's trophic role. Quite often, a single type of organism can be placed in more than one functional feeding category. The main functional feeding groups considered in our analysis were:

- Collectors (filterers),
- Collectors (gatherers),
- Scrapers and grazers,
- Shredders,
- Piercer herbivores,
- Predators (engulfers),
- Predators (piercers), and
- Scavengers and omnivores.

The tabular FFG listings provided by Merritt and Cummins (1996) were used to assign taxa to FFG categories. Only taxa for which a feeding group had been determined were used in this analysis. For each site, the total number of taxa and the total number of organisms in each functional feeding group was calculated. The mean total number of taxa and the mean total number of organisms in each taxon, for each sub-basin, were also calculated.

These values were then plotted to compare the proportions of organisms in each functional feeding group among the different sampled sites and sub-basins.

2.3.3 Hilsenhoff Biotic Index

The Hilsenhoff Biotic Index (HBI) was originally developed for assessing the biotic impacts of low dissolved oxygen levels resulting from organic loading in Midwestern streams. Use of the HBI has subsequently been expanded to monitor the impacts of impoundment, thermal pollution, and certain types of chemical pollution. In general, the HBI is a measure of response of macroinvertebrate assemblages to organic (nutrient) enrichment. It is calculated by multiplying the number of individuals of each taxon by the taxon's assigned tolerance value (Hilsenhoff, 1987), totaling these products, and dividing the result by the total number of individuals of each taxon assigned a tolerance value.

$$HBI = \Sigma\, (n_i a_i)/N$$

Where: *n* is the number of individuals of the *i*th taxon;

a is the tolerance index value of that taxon;

N is the total number of individuals in the sample assigned a HBI value.

The range of HBI values is 0-10, with 0 indicating pollution intolerance, and 10 indicating high pollution tolerance (Appendices C, D).

2.3.4 Shannon-Weiner Diversity Index

A wide variety of diversity indices are available for use in characterizing the taxonomic diversity of benthic macroinvertebrate communities. Examples include Simpson's Index, the Brillouin Index, and the Shannon-Weiner Index (Krebs, 1989). We selected the Shannon-Weiner index (SWDI, or H) for comparison with the B-IBI because it is simple to calculate and has been used extensively to characterize biological communities. Unlike B-IBI values, H-values do not incorporate consideration of pollution tolerance, long-livedness, or feeding group. H increases with the number of taxa in a sample, as well as the proportion of the sample that each taxon contributes. It is calculated as follows:

$$H = \Sigma\, (p_i)(\log_2 p\mathrm{i}_i)$$

Where: *p* is the proportion of the total sample belonging to the *i*th taxon.

We calculated H-values for each of the benthic macroinvertebrate samples in order to compare it to the B-IBI (Appendix D).

2.4 STATISTICAL ANALYSES

We applied Levenes test (SPSS, 2003) to the B-IBI data, and found that variances in B-IBI score differed significantly ($p<0.05$) among sub-basins. This necessitated our using a non-parametric Kruskal-Wallace test to identify whether mean sub-basin B-IBI scores differed significantly ($p<0.05$). When significant differences were found, *post hoc* comparisons between sub-basin means were made using paired T-tests (SPSS, 2003), which do not assume equality of variances among sampled populations. Significant differences in mean sub-basin B-IBI scores were displayed in a data matrix (Table 4).

Correlations between B-IBI scores and the various invertebrate community indices, and between B-IBI scores and the physical parameters that could affect invertebrate communities (i.e., land-use, water quality parameters, hydrological parameters) were calculated as Spearman rank correlation coefficients (Daniel, 1990) using SPSS v.12 statistical software. Correlation coefficients were displayed in tabular matrices, which also indicated the significance of any observed correlations.

3. RESULTS AND DISCUSSION

3.1 SUB-BASIN COMPARISONS OF B-IBI SCORES

3.1.1 Sub-Basin B-IBI-Scores

Mean (± standard deviation) sub-basin B-IBI scores ranged from a high of 37.8 ± 5.8 (Issaquah) to a low of 14.8 ± 5.0 (Duwamish) (Table 4), and differed significantly among watersheds ($df = 9$, $F = 6.972$, $p<0.001$). This range of B-IBI values is similar to the range of mean B-IBI scores (15.5-46.5) measured in nine sub-basins in the Greater Vancouver Regional District, British Columbia, Canada, by EVS (2000).

Paired T-test comparisons demonstrated that, in general, the mean B-IBI scores of the sub-basins with the highest scores (e.g., Issaquah, Deep/Coal) were significantly different than the scores of most of the other sub-basins, and that scores of the lowest-scored sub-basins (e.g., Sammamish River tributaries, North/Swamp Creeks, West Lake Washington, Black, Duwamish) (Table 5). Statistically significant differences in mean B-IBI scores among certain sub-basins indicate that there is greater variability in B-IBI scores *between* sub-basins than within individual sub-basins. In subsequent sections of this report, we will discuss the nature of the differences among sub-basins, and environmental factors which are causing these differences.

Table 4: Mean (± standard deviation) B-IBI scores, total number of taxa present, number of EPT taxa present, and SWDI and HBI values for 20 sub-basins in the Green-Duwamish and Greater Lake Washington watersheds, based upon samples collected in 2002.

WATERSHED	SUB-BASIN	N	MEAN B-IBI SCORE (± STD. DEV.)	MEAN TOTAL NO. OF TAXA (± STD.DEV.)	MEAN NO. OF EPT TAXA (± STD.DEV.)	MEAN SWDI (± STD. DEV.)	MEAN HBI (± STD. DEV.)
G. Lk. Wa.	Issaquah	8	37.8 ± 5.8	30.9 ± 6.5	20.4 ± 4.9	3.7 ± 0.3	3.9 ± 1.1
Green-Duwamish	Deep/Coal Basin	6	35.3 ± 5.5	34.5 ± 2.4	21.0 ± 3.6	3.7 ± 0.4	4.6 ± 0.9
Green-Duwamish	Newaukum	9	30.4 ± 8.3	31.2 ± 6.4	16.8 ± 5.0	3.3 ± 0.8	4.7 ± 0.6
Green-Duwamish	Middle Green	9	30.2 ± 9.1	28.3 ± 7.0	15.4 ± 6.5	3.3 ± 0.7	5.0 ± 1.0
G. Lk. Wa.	Bear Creek	11	28.5 ± 4.3	28.8 ± 3.9	15.2 ± 3.3	3.7 ± 0.3	4.7 ± 0.6
Green-Duwamish	Covington Basin	7	28.3 ± 4.4	27.7 ± 4.8	15.6 ± 4.2	3.6 ± 0.4	4.7 ± 0.9
G. Lk. Wa.	Cedar River	11	28.0 ± 10.5	26.2 ± 10.4	14.6 ± 7.8	3.1 ± 0.8	5.5 ± 1.6
Green-Duwamish	Soos	10	26.6 ± 8.5	25.8 ± 6.1	14.7 ± 5.5	3.2 ± 0.6	4.8 ± 0.9
G. Lk. Wa.	Evans Creek	10	26.6 ± 4.9	27.3 ± 4.7	14.0 ± 4.1	3.2 ± 0.5	5.5 ± 0.7
G. Lk. Wa.	Little Bear	7	26.3 ± 3.1	26.3 ± 3.3	14.1 ± 3.8	3.6 ± 0.4	5.3 ± 0.7
Green-Duwamish	Jenkins	3	24.0 ± 5.3	27.0 ± 3.0	15.0 ± 4.4	3.1 ± 0.6	5.8 ± 0.7
Green-Duwamish	Mill Creek	5	22.0 ± 6.0	23.0 ± 4.3	10.8 ± 4.1	2.7 ± 0.6	5.0 ± 0.9
G. Lk. Wa.	L. Sammamish Tribs	10	21.4 ± 7.7	22.3 ± 6.3	9.3 ± 5.4	2.9 ± 0.7	6.3 ± 1.1
G. Lk. Wa.	E. Lake Washington	9	21.3 ± 7.2	20.2 ± 5.4	8.0 ± 5.5	2.8 ± 0.8	5.4 ± 0.9
Green-Duwamish	Lower Green	5	18.8 ± 9.5	19.4 ± 9.4	8.4 ± 6.9	2.5 ± 0.7	6.2 ± 1.3
G. Lk. Wa.	Samm River Tribs	11	17.6 ± 8.0	17.2 ± 6.4	5.9 ± 4.3	2.6 ± 0.7	6.7 ± 0.9
G. Lk. Wa.	North/Swamp Creeks	5	17.2 ± 7.2	17.4 ± 6.7	6.4 ± 6.1	2.6 ± 0.9	6.7 ± 1.1
G. Lk. Wa.	W. Lake Washington	9	16.0 ± 4.6	18.0 ± 6.6	6.9 ± 4.7	2.5 ± 0.4	6.4 ± 1.1
Green-Duwamish	Black	11	15.8 ± 4.8	17.6 ± 5.2	6.0 ± 3.9	2.5 ± 0.6	6.2 ± 1.3
Green-Duwamish	Duwamish	5	14.8 ± 5.0	16.2 ± 5.1	5.2 ± 4.0	2.3 ± 0.4	6.8 ± 0.4

Table 5: Results of paired comparisons among sub-basin mean B-IBI scores for 20 sub-basins in the Green-Duwamish and Greater Lake Washington watersheds, based upon samples collected in 2002. ● = means significantly different (p<0.05).

		ISS	DEE	NEW	MID	BEA	COV	CED	SOO	EVA	LIT	JEN	MIL	LAK	EAS	LOW	SAM	NOR	WES	BLA	DUW
		37.8	35.3	30.4	30.2	28.5	28.3	28.0	26.6	26.6	26.3	24.0	22.0	21.4	21.3	18.8	17.6	17.2	16.0	15.8	14.8
ISS	37.8					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
DEE	35.3								●	●	●	●	●	●	●	●	●	●	●	●	●
NEW	30.4														●		●	●	●	●	●
MID	30.2																●	●	●	●	●
BEA	28.5															●		●	●	●	●
COV	28.3															●		●	●	●	●
CED	28.0																	●	●	●	●
SOO	26.6																	●	●	●	●
EVA	26.6																	●	●	●	●
LIT	26.3																	●	●	●	●
JEN	24.0																				
MIL	22.0																				
LAK	21.4																				
EAS	21.3																				
LOW	18.8																				
SAM	17.6																				
NOR	17.2																				
WES	16.0																				
BLA	15.8																				
DUW	14.8																				

BLA	Black	COV	Covington Basin
DUW	Duwamish	EVA	Evans Creek
WES	West Lake Washington	BEA	Bear Creek
SAM	Sammamish River Tribs.	LAK	Lake Sammamish Tribs.
LOW	Lower Green	SOO	Soos
NOR	North/Swamp Creeks	NEW	Newaukum
EAS	East Lake Washington	CED	Cedar River
LIT	Little Bear	MID	Middle Green
JEN	Jenkins	DEE	Deep/Coal Basin
MIL	Mill Creek	ISS	Issaquah

3.1.2 Differences in B-IBI-Rankings Among Sub-Basins

Of the 20 sub-basins sampled, seven were ranked as having "fair" mean B-IBI scores, three "fair-poor", seven "poor", and three "very poor" (Table 6) using the SalmonWeb ranking criteria. However, the average B-IBI ranking for a sub-basin does not necessarily reflect the proportions of sampled watercourses within the sub-basin having "good", "fair", "fair-poor", "poor", or "very poor" rankings (Figure 2). For example, the majority of sites within the Issaquah sub-basin had "good" B-IBI rankings, but the average sub-basin ranking was reduced to "fair" because one of the sites within the watershed had a "poor" ranking. The B-IBI scores indicate that most of the watercourses in the Issaquah watershed are in relatively good biological condition, whereas most of the watercourses in the Duwamish and Black sub-basin are in poor condition (Figure 2).

Table 6: Sub-basin rankings based on B-IBI and HBI scores for 20 sub-basins in the Green-Duwamish and Greater Lake Washington watersheds, based upon samples collected in 2002.

Sub-Basin	Mean B-IBI (± Std. Dev.)	B-IBI Range	Average B-IBI Ranking	Mean HBI (± Std. Dev.)	HBI Range	Average HBI Ranking
Issaquah	37.8 ± 5.8	24-42	Fair	3.9 ± 1.1	2.4-5.5	Very Good
Deep/Coal Basin	35.3 ± 5.5	30-44	Fair	4.6 ± 0.9	3.7-6.1	Good
Newaukum	30.4 ± 8.3	20-40	Fair	4.7 ± 0.6	3.9-5.6	Good
Middle Green	30.2 ± 9.1	16-42	Fair	5.0 ± 1.0	3.7-6.8	Good
Bear Creek	28.5 ± 4.3	20-34	Fair	4.7 ± 0.6	3.8-5.8	Good
Covington Basin	28.3 ± 4.4	22-34	Fair	4.7 ± 0.9	3.7-6.3	Good
Cedar River	28.0 ± 10.5	12-40	Fair	5.5 ± 1.6	2.3-7.3	Good
Soos	26.6 ± 8.5	12-38	Fair-Poor	4.8 ± 0.9	3.6-6.2	Good
Evans Creek	26.6 ± 4.9	16-32	Fair-Poor	5.5 ± 0.7	4.1-6.5	Good
Little Bear	26.3 ± 3.1	22-32	Fair-Poor	5.3 ± 0.7	4.3-6.2	Good
Jenkins	24.0 ± 5.3	20-30	Poor	5.8 ± 0.7	5.2-6.6	Fair
Mill Creek	22.0 ± 6.0	14-28	Poor	5.0 ± 0.9	3.6-5.8	Good
L. Sammamish Tribs	21.4 ± 7.7	10-38	Poor	6.3 ± 1.1	4.6-7.8	Fair
E. Lake Washington	21.3 ± 7.2	10-30	Poor	5.4 ± 0.9	4.0-6.7	Good
Lower Green	18.8 ± 9.5	10-34	Poor	6.2 ± 1.3	4.8-8.1	Fair
Samm River Tribs	17.6 ± 8.0	10-36	Poor	6.7 ± 0.9	4.6-8.1	Fair-Poor
North/Swamp Creeks	17.2 ± 7.2	10-28	Poor	6.7 ± 1.1	5.6-8.2	Fair-Poor
W. Lake Washington	16.0 ± 4.6	10-22	Very Poor	6.4 ± 1.1	5.0-8.0	Fair
Black	15.8 ± 4.8	10-24	Very Poor	6.2 ± 1.3	3.9-8.3	Fair
Duwamish	14.8 ± 5.0	10-22	Very Poor	6.8 ± 0.4	6.3-7.4	Fair-Poor

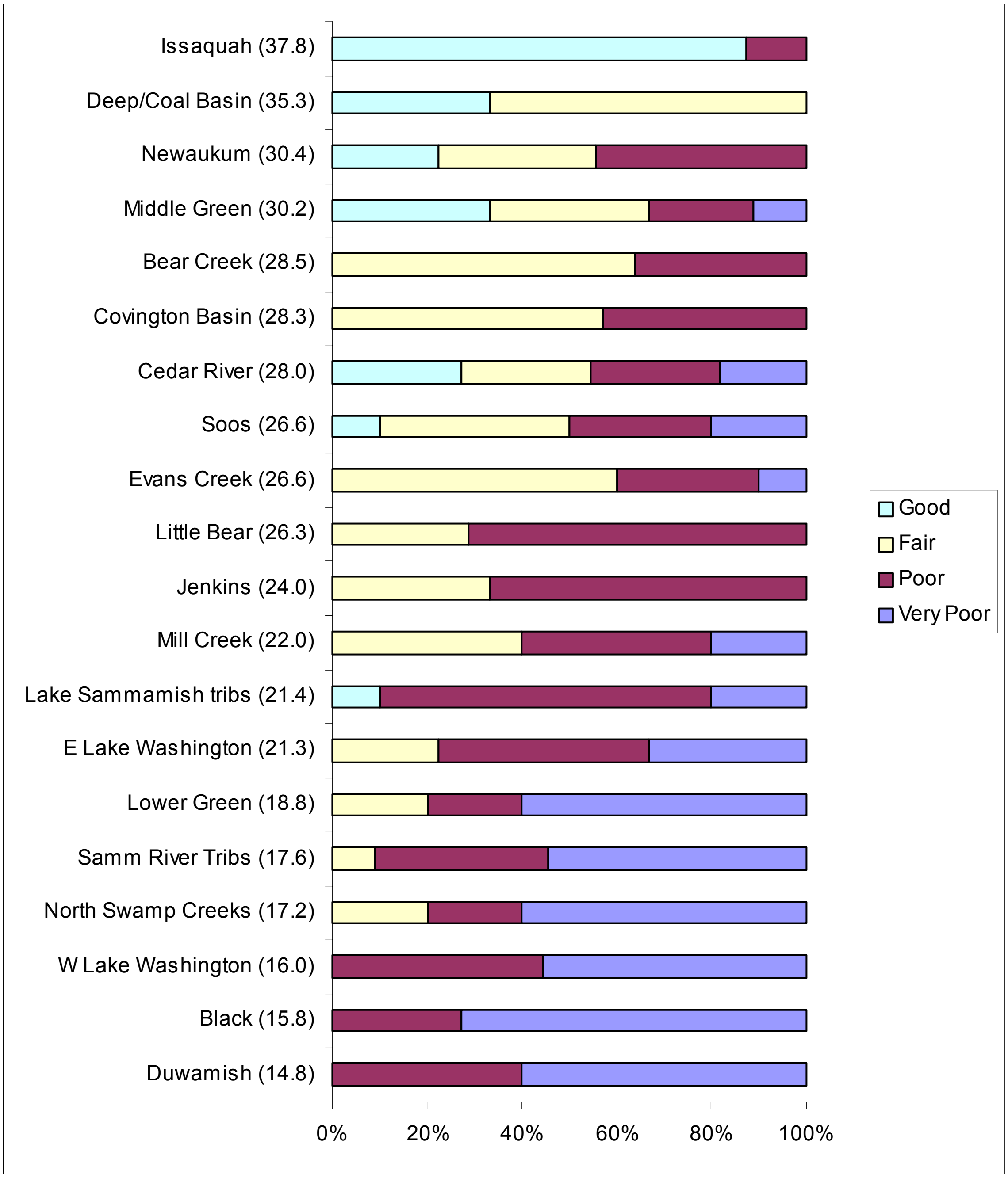
B-IBI Rankings:

46-50 – Excellent
38-44 – Good
28-36 – Fair
18-26 – Poor
10-16 – Very Poor

HBI Rankings:

0.00-3.50 – Excellent
3.51-4.50 – Very Good
4.51-5.50 – Good
5.51-6.50 – Fair
6.51-7.50 – Fair-Poor
7.51-8.50 – Poor
8.51-10.00 – Very Poor

Figure 2: Mean percentages of watershed in each sub-basin that have “good”, “fair”, “poor”, and “very poor” rankings, based on B-IBI scores. Sub-basins are sorted by mean B-IBI scores (in parentheses).



3.2 B-IBI SCORES AND OTHER INDICES

In general, there are strong significant correlations between a sample's B-IBI score and the total number of invertebrate taxa present in the sample (r_s = 0.921, p<0.001), and between a sample's B-IBI score and the total number of EPT taxa present (r_s = 0.946, p<0.001). Strong, but slightly weaker, correlations exist between a sample's B-IBI score and its Shannon-Weiner Diversity Index (SWDI; r_s = 0.801, p<0.001) and Hilsenhoff Biotic Index (HBI, r_s =-0.786, p<0.001).

Like the B-IBI, Hilsenhoff's HBI incorporates pollution sensitivity rankings. HBI rankings of the various sub-basins generally paralleled B-IBI rankings (Table 6), but tended to score sub-basins as being in better biological condition than did equivalent B-IBI rankings.

There are also strong significant correlations between mean sub-basin B-IBI scores and mean total numbers of taxa present (r_s = 0.960, p<0.001), mean numbers of EPT taxa present (r_s = 0.962, p<0.001), mean SWDI (r_s = 0.921, p<0.001) and mean HDI values (r_s = -0.888, p<0.001) for each sub-basin (Figures 3a, 3b, 3c and 3d, respectively; Table 4).

It is not surprising that strong correlations exist between B-IBI score and total number of taxa, and between B-IBI score and number of EPT taxa, as values for these variables are used in calculating a B-IBI score. Similarly, the correlation between B-IBI scores and SWDI values is also not surprising, since both of these values measure community diversity. Despite the HBI's relative simplicity compared to the B-IBI, HBI values are significantly correlated with the B-IBI (Figure 3d). Note that B-IBI score is negatively correlated with HBI score, because the B-IBI measures biotic *integrity* (i.e., similarity to biological conditions considered "good"), whereas the HBI measures biotic *perturbation*.

Figure 3 a: Sub-basin mean (± standard deviation) B-IBI scores vs. mean numbers of taxa.

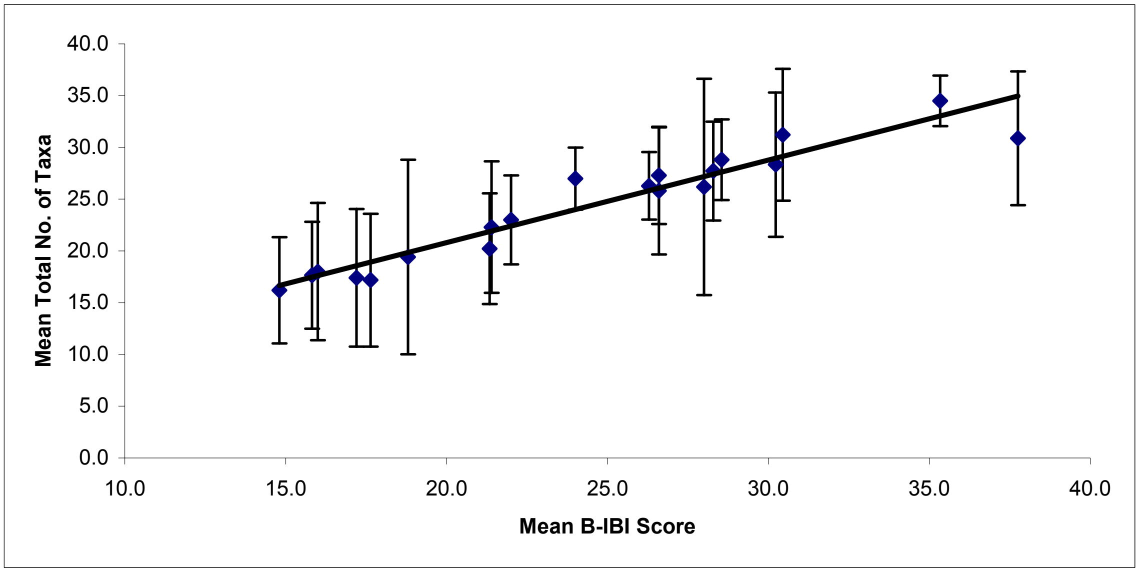


Figure 3 b: Sub-basin mean (± standard deviation) B-IBI scores vs. mean numbers of EPT taxa.

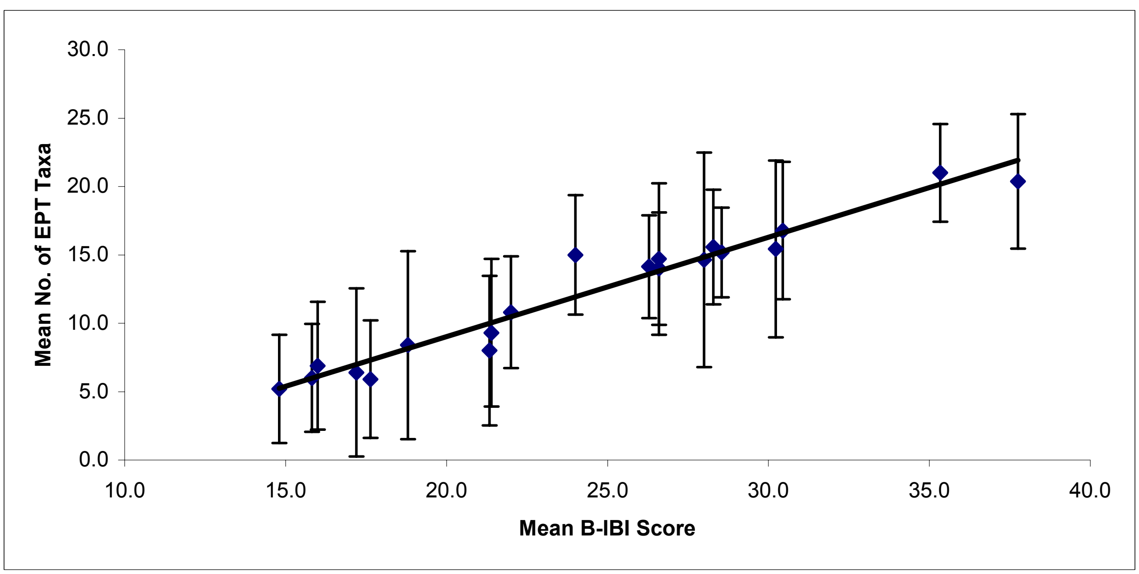


Figure 3 c: Sub-basin mean (± standard deviation) B-IBI score vs. mean Shannon-Weiner Diversity Index (H) score.

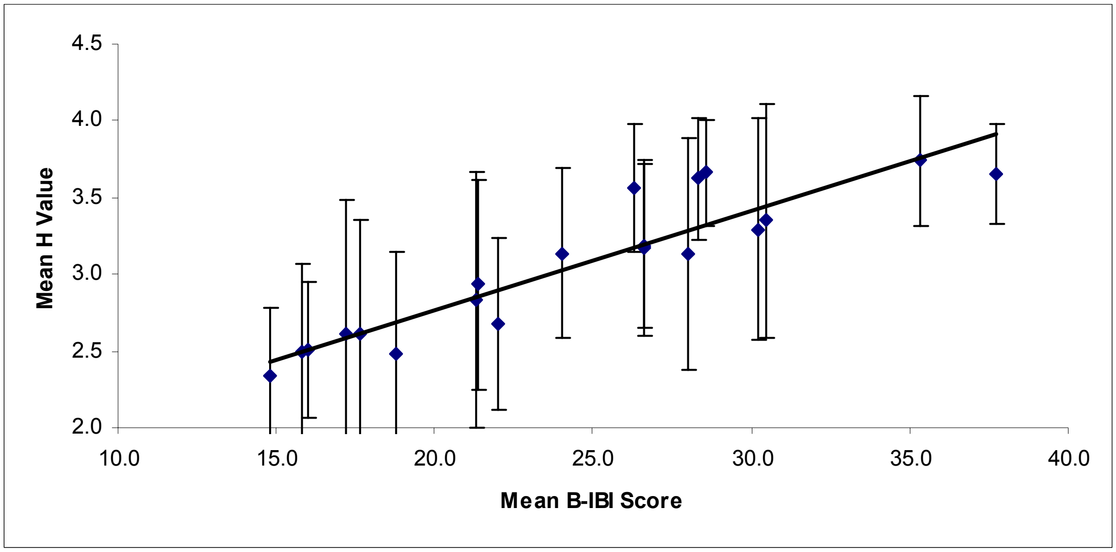
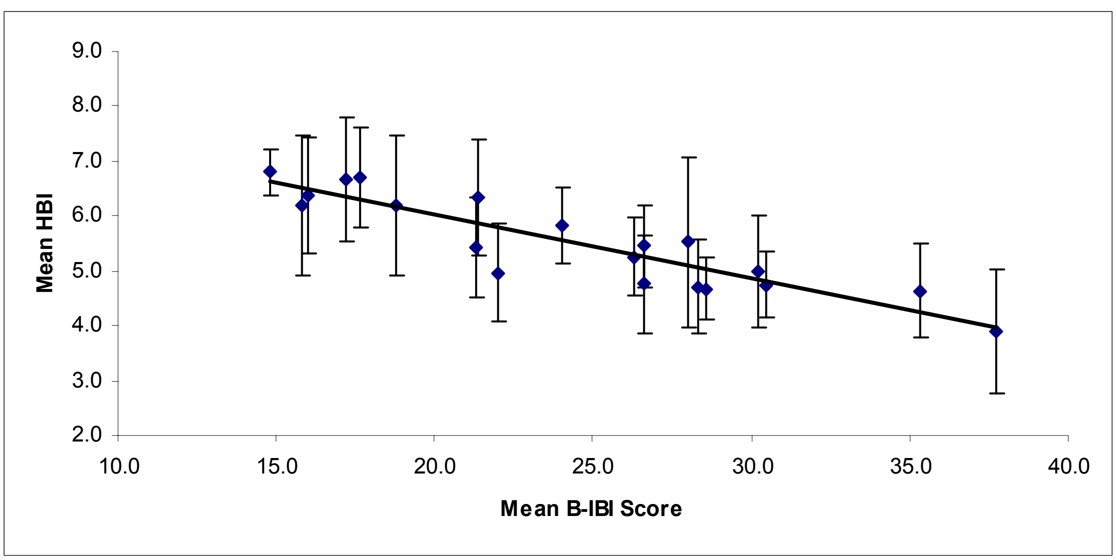


Figure 3 d: Sub-basin mean (± standard deviation) B-IBI score vs. mean Hilsenhoff Biotic Index (HBI) score.



3.3 B-IBI AND FUNCTIONAL FEEDING GROUPS

There is neither an apparent trend nor a significant correlation between the B-IBI score of a given site and the proportions of organisms in the various functional feeding groups (Table 7). However, the proportion of predator taxa at a site is significantly correlated with the proportion of collector taxa present and, similarly, the proportion of piercer predators is strongly correlated with the proportion of engulfer predators in a sample. The mean proportions of organisms in the various functional feeding groups are generally quite similar among sub-basins, despite the wide variation among sub-basins in B-IBI scores and other measures of community diversity (Table 8, Figure 4). It appears that although the composition and diversity of benthic macroinvertebrate communities vary widely among communities, the community structure, in terms of the proportion of organisms in each feeding group, remains similar.

Overall, collector-gatherers were most abundant in the samples (60%), followed by collector-filterers (48%), predator-engulfers (39%), piercers and scrapers (38%), and predator/piercers (28%). Shredders and herbivore-piercers were relatively uncommon in the samples, on average comprising 7.1% and 0.4% of the classifiable organisms collected.

Table 7: Spearman rank correlation coefficients for site-level B-IBI scores and percentages of organisms at each site in different functional feeding groups (n=158).

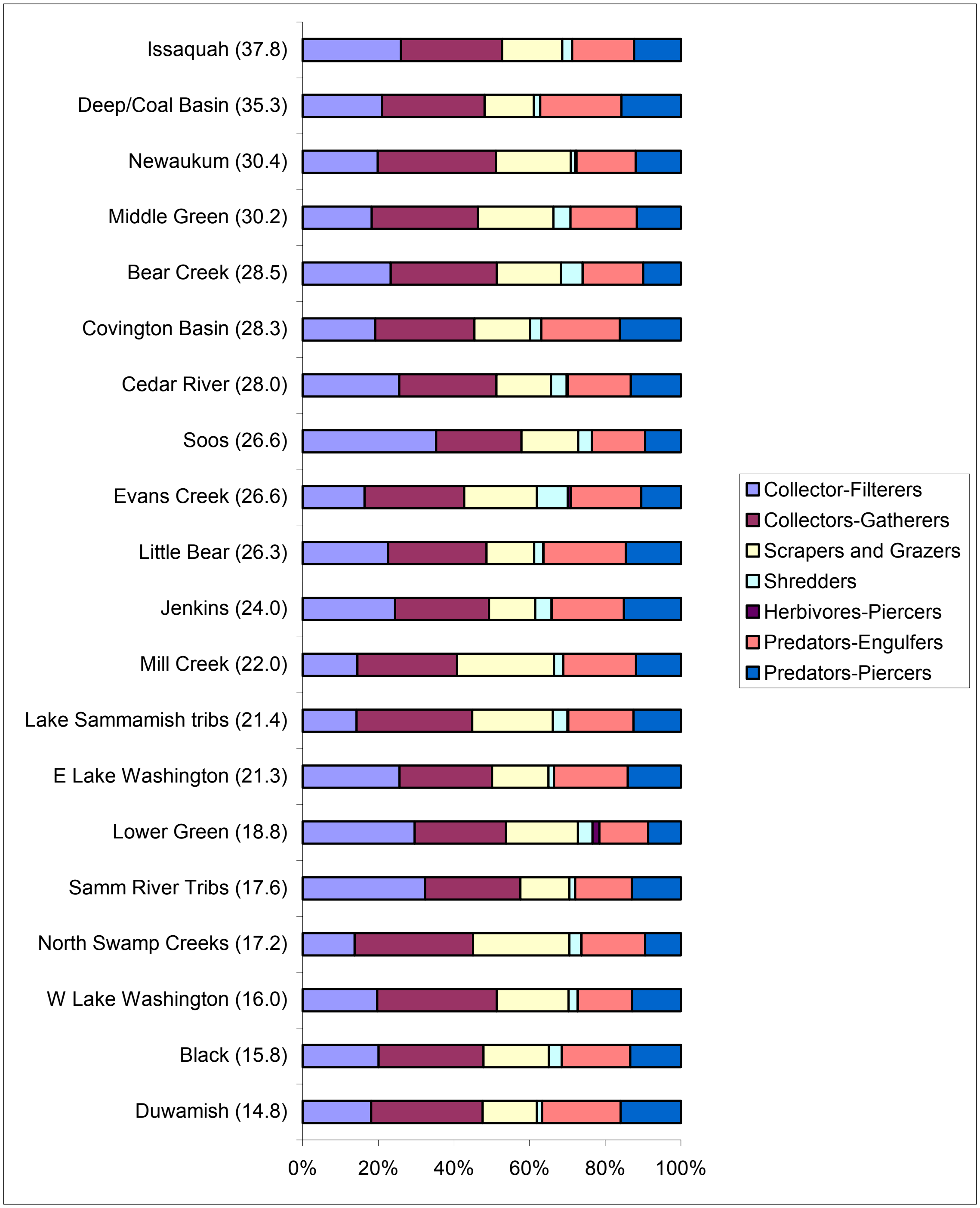
	Collectors-Filterers	Collectors-Gatherers	Scrapers and Grazers	Shredders	Herbivores-Piercers	Predators-Engulfers	Predators-Piercers
B-IBI Score	0.026	0.037	-0.042	0.077	-0.041	0.091	0.133
Collectors-Filterers		-0.112	-0.828**	-0.246**	-0.052	0.228**	0.408**
Collectors-Gatherers			-0.198*	-0.200*	0.062	0.471**	0.600**
Scrapers and Grazers				0.011	0.105	0.438**	-0.414**
Shredders					-0.064	0.096	-0.051
Herbivores-Piercers						-0.092	-0.015
Predators-Engulfers							0.898**

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

Table 8: Proportions of taxa in each functional feeding group for 20 sub-basins in the Green-Duwamish and Greater Lake Washington watersheds, based upon samples collected in 2002. Note, only taxa assigned to a functional feeding group by Merritt and Cummins (1997) were included in this analysis.

Sub-Basin	B-IBI	Collector-Filterers	Collectors-Gatherers	Scrapers and Grazers	Shredders	Herbivores-Piercers	Predators-Engulfers	Predators-Piercers
Issaquah	37.8 ± 5.8	55.9 ± 20.3	57.7 ± 18.5	34.2 ± 21.1	5.6 ± 5.1	0.0 ± 0.0	35.4 ± 18.6	26.6 ± 16.2
Deep/Coal Basin	35.3 ± 5.5	49.6 ± 16.5	64.2 ± 24.7	30.8 ± 12.5	4.0 ± 2.6	0.0 ± 0.1	50.7 ± 22.6	37.2 ± 25.0
Newaukum	34.0 ± 8.2	44.6 ± 23.9	70.2 ± 20.6	44.4 ± 18.9	2.7 ± 4.8	0.8 ± 0.8	35.2 ± 9.0	26.8 ± 6.6
Middle Green	30.2 ± 9.1	39.8 ± 16.2	61.2 ± 11.8	43.4 ± 17.2	9.8 ± 7.6	0.0 ± 0.1	38.1 ± 19.7	25.4 ± 16.0
Bear Creek	28.5 ± 4.3	47.9 ± 23.2	57.7 ± 25.3	35.1 ± 15.9	11.7 ± 12.8	0.1 ± 0.3	32.9 ± 19.0	20.5 ± 16.2
Covington Basin	28.3 ± 4.4	47.8 ± 24.6	65.3 ± 18.0	36.5 ± 21.2	7.4 ± 7.8	0.0 ± 0.0	51.7 ± 18.6	40.2 ± 22.1
Cedar River	28.0 ± 10.5	57.4 ± 25.7	58.0 ± 25.1	32.3 ± 24.7	9.4 ± 8.9	0.7 ± 2.2	37.4 ± 24.9	29.9 ± 23.8
Soos	26.6 ± 8.5	63.7 ± 21.3	40.8 ± 21.4	27.0 ± 21.5	6.6 ± 3.6	0.0 ± 0.0	25.4 ± 17.7	17.0 ± 13.0
Evans Creek	26.6 ± 4.9	34.3 ± 19.5	55.3 ± 26.5	40.3 ± 14.7	17.0 ± 2.5	1.7 ± 0.1	39.1 ± 22.4	22.0 ± 24.9
Little Bear	26.3 ± 3.1	53.0 ± 28.5	61.1 ± 26.6	29.4 ± 26.3	5.7 ± 6.1	0.1 ± 0.2	51.0 ± 30.8	34.2 ± 32.2
Lake Sammamish Tribs.	25.3 ± 6.9	34.8 ± 15.9	74.4 ± 19.3	51.9 ± 23.0	9.5 ± 11.2	0.4 ± 0.8	42.0 ± 22.5	30.5 ± 15.0
Jenkins	24.0 ± 5.3	58.3 ± 23.8	59.0 ± 13.7	29.2 ± 22.5	10.2 ± 3.7	0.1 ± 0.2	45.4 ± 20.5	35.9 ± 28.2
Mill Creek	22.0 ± 6.0	29.9 ± 12.9	54.4 ± 20.4	52.9 ± 17.1	5.0 ± 4.2	0.0 ± 0.0	39.7 ± 15.2	24.5 ± 12.1
East Lake Washington	21.3 ± 7.2	55.1 ± 19.5	52.7 ± 26.5	32.2 ± 14.7	3.1 ± 2.5	0.0 ± 0.1	41.9 ± 22.4	30.3 ± 24.9
Lower Green	18.8 ± 9.5	54.4 ± 26.1	44.4 ± 23.8	34.8 ± 22.8	7.1 ± 4.7	3.4 ± 7.4	23.6 ± 12.8	15.9 ± 13.4
Samm River Tribs	17.6 ± 8.0	67.3 ± 21.4	52.4 ± 24.1	26.8 ± 19.3	3.2 ± 2.6	0.1 ± 0.2	31.1 ± 25.6	27.0 ± 26.9
North/Swamp Creeks	17.2 ± 7.2	27.3 ± 5.7	62.1 ± 16.9	50.6 ± 13.6	6.2 ± 6.3	0.1 ± 0.2	33.4 ± 15.6	18.8 ± 4.6
West Lake Washington	16.0 ± 4.6	47.4 ± 27.2	75.9 ± 15.7	45.7 ± 27.8	5.7 ± 6.5	0.1 ± 0.4	34.4 ± 26.9	31.0 ± 25.8
Black	15.8 ± 4.8	45.8 ± 26.6	63.0 ± 17.5	39.3 ± 21.3	7.8 ± 11.1	0.0 ± 0.0	41.3 ± 29.3	30.4 ± 28.9
Duwamish	14.8 ± 5.0	47.5 ± 16.1	77.0 ± 10.0	37.6 ± 9.8	3.6 ± 4.1	0.0 ± 0.1	54.3 ± 19.0	41.8 ± 16.0

Figure 4: Mean percentages of organisms in each functional feeding group for the 20 sampled sub-basins. Sub-basins are sorted by mean B-IBI score (in parentheses).



3.4 B-IBI Scores and Land-Use Parameters

In general, a watershed's B-IBI score is closely correlated with the land-use practices within the watershed, whether this is measured in terms of the percentage Effective Impervious Area (%EIA) in the watershed, or the proportion of a watershed that is occupied by different types of development.

3.4.1 B-IBI vs. %EIA

At the site level, as %EIA increases, B-IBI score decreases, and this relationship is significant (r_s = -0.441, p<0.01; Figure 5a). At the sub-basin level, the relationship between mean B-IBI score and mean %EIA is also significant, and much stronger (r_s = -0.868, p<0.01; Figure 5b). In the Greater Vancouver Regional District, British Columbia, Canada, EVS (2000) also found a significant negative relationship between a watershed's %EIA and its B-IBI score (r^2 = -0.959, p<0.05 using Pearson's correlation coefficient). The sampled watersheds in King County and Vancouver include a similar range of land-use types, and a similar range of %EIA values.

Figure 5 a: Individual site B-IBI scores vs. mean % EIA.

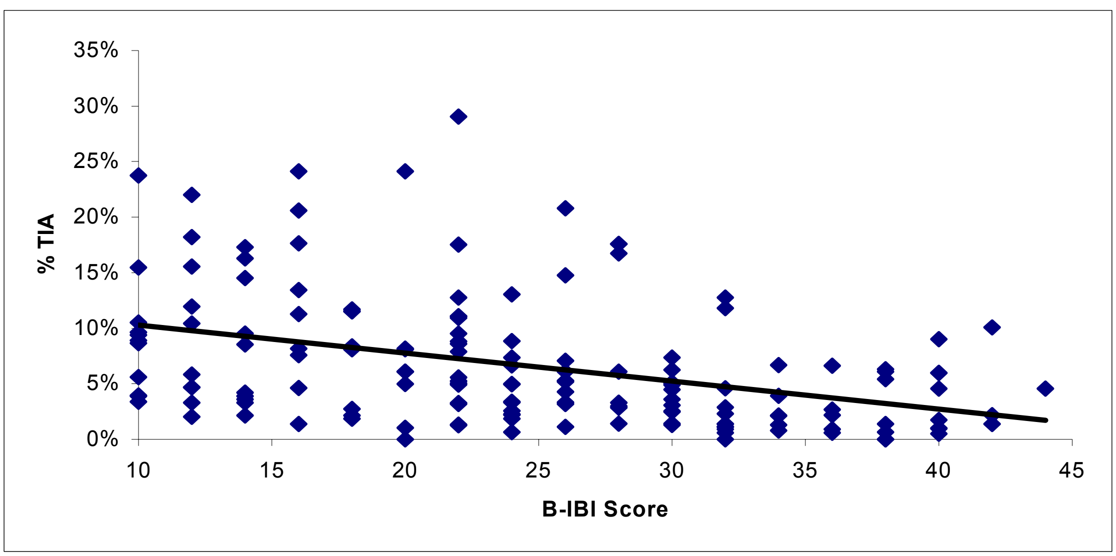
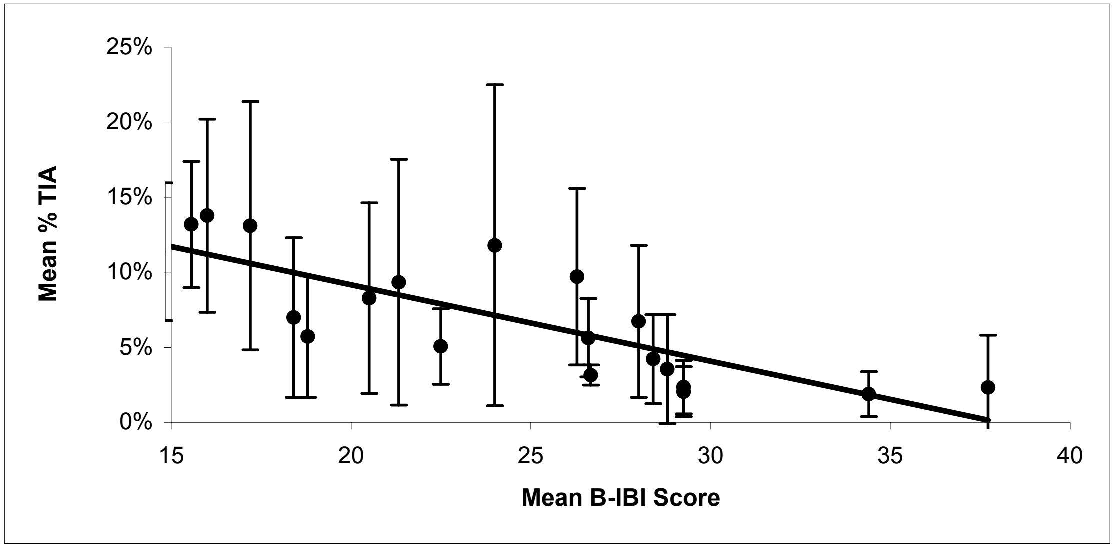


Figure 5 b: Mean (± standard deviation) sub-basin B-IBI scores vs. mean % EIA.



3.4.2 B-IBI vs. Upstream Land Use

Upstream land-use significantly affects individual site B-IBI scores, as well as the mean B-IBI scores of sub-basins (Tables 9 and 10; Figure 6). At both site and sub-basin levels, B-IBI is significantly positively correlated with the amount of forest ($r_s = 0.930$, $p<0.01$) and scrub/shrub ($r_s = -0.698$, $p<0.01$) present in a watershed. Conversely, there is a significant negative correlation between B-IBI score and the amount of developed land (i.e., bare ground/asphalt [$r_s = -0.818$, $p<0.01$], bare rock/concrete [$r_s = -0.728$, $p<0.01$], and high [$r_s = -0.851$, $p<0.01$], medium [$r_s = -0.934$, $p<0.01$], and low-intensity development [$r_s = -0.514$, $p<0.05$]) (Tables 9 and 10).

At the site and sub-basin levels, the strongest correlations observed were between B-IBI score and the amount of medium-intensity development, and between B-IBI score and the amount of forested land. B-IBI scores are also correlated with most of the other land-use variables, but are least strongly correlated with the amount of grassland ($r_s = -0.266$, $p>0.05$) and open water ($r_s = 0.368$, $p>0.05$) in a watershed. Our results confirm the observations of the USGS (Lenz and Rheaume, 2000), that B-IBI scores of forest streams are inversely related with the amount of a watershed that has been logged. Our results are also supported by the findings of Bennett and Rysavy (2003), and Yoder (1991), who found that B-IBI scores decreased as watersheds became more urbanized (e.g., more residential and industrial development, more road crossings, more stormflow discharges).

It should be noted the amount of developed area (bare ground/asphalt, bare rock/concrete, and high, medium, and low-intensity development) in a watershed is inversely proportional to the amount of undeveloped area (forest and shrub/scrub). This is to be expected when forested area is cleared for development. Many of the development-related land-use variables are correlated with one another, which is not surprising since a increase in developed area is accompanied by an increase in paved area, and so on.

Table 9: Spearman rank correlation coefficients for site-level B-IBI scores and percentages of watersheds occupied by various land-use types (n=158).

	Bare Ground/ Asphalt	Bare Rock/ Concrete	Developed - High Intensity	Developed - Medium Intensity	Developed - Low Intensity	Forest	Scrub/ Shrub	Grass	Open Water
B-IBI Score	-0.558**	-0.435**	-0.593**	-0.772**	-0.463**	0.741**	0.466**	-0.292**	0.248**
Bare Ground/Asphalt		0.800**	0.906**	0.775**	0.344**	-0.709**	-0.330**	0.380**	-0.036
Bare Rock/Concrete			0.775**	0.567**	0.236**	-0.557**	-0.150	0.351**	-0.066
Developed - High Intensity				0.804**	0.386**	-0.785**	-0.333**	-0.385**	-0.024
Developed - Med. Intensity					0.571**	-0.893**	-0.573**	0.292**	-0.187*
Developed - Low Intensity						-0.672**	-0.191**	0.276**	-0.164*
Forest							0.434**	-0.407**	0.259**
Scrub/Shrub								0.279**	0.376**
Grass									-0.074
Open Water									

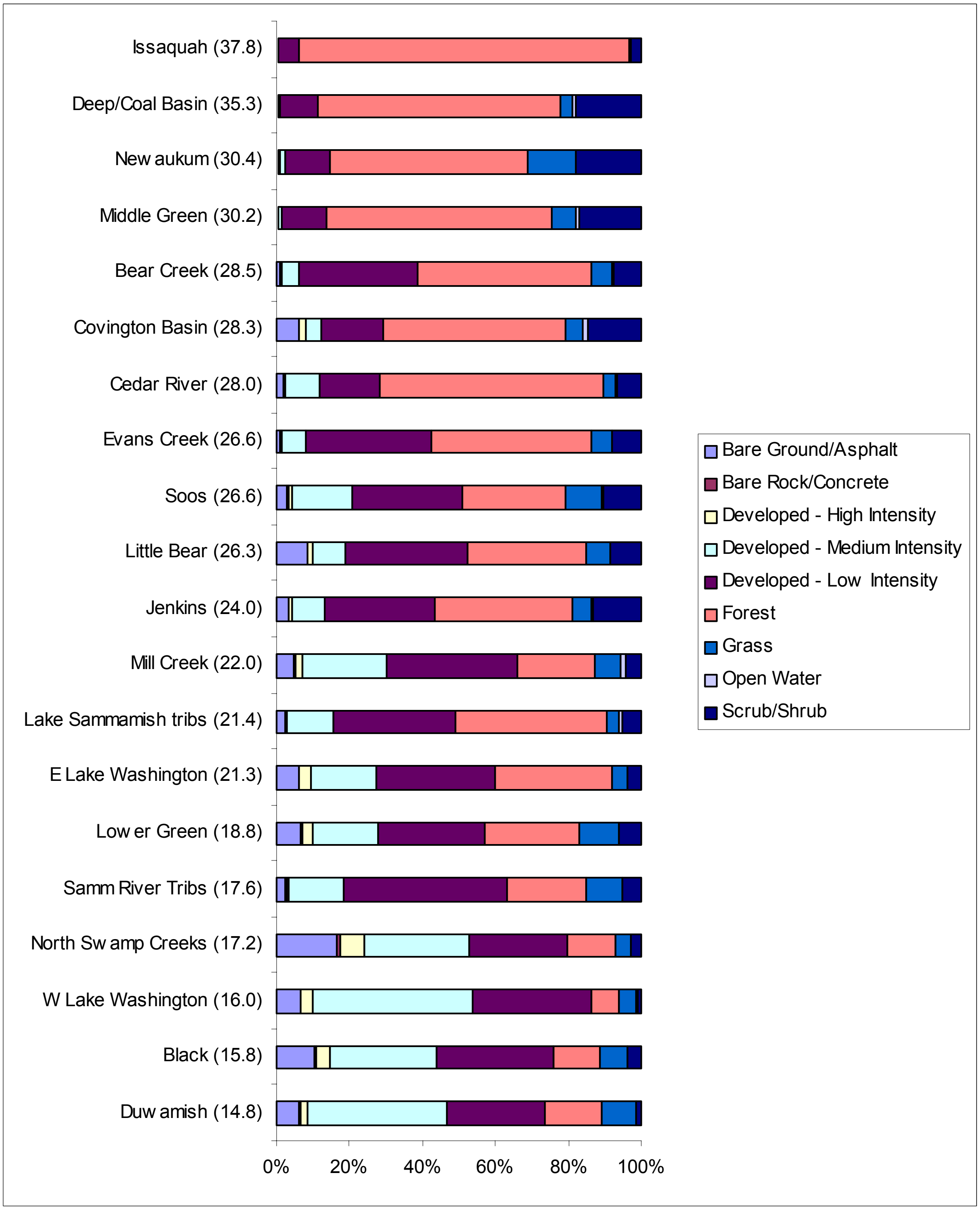
** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

Table 10: Spearman rank correlation coefficients for sub-basin-level mean B-IBI scores and mean percentages of sub-basins occupied by various land-use types (n=20).

	Bare Ground/ Asphalt	Bare Rock/ Concrete	Developed - High Intensity	Developed - Medium Intensity	Developed - Low Intensity	Forest	Scrub/ Shrub	Grass	Open Water
B-IBI Score	-0.818**	-0.728**	-0.851**	-0.934**	-0.514*	0.930**	0.698**	0.266	0.368
Bare Ground/Asphalt		0.892**	0.950**	0.792**	0.361	-0.836**	-0.517*	0.244	-0340
Bare Rock/Concrete			0.920**	0.753**	0.314	-0.777**	-0.505*	0.298	-0.266
Developed - High Intensity				0.871**	0.385	-0.893**	-0.586**	0.221	-0.208
Developed – Med. Intensity					0.469*	-0.941**	-0.725**	0.253	-0.263
Developed - Low Intensity						-0.567**	-0.284	0.238	-0.150
Forest							0.644**	-0.386	0.322
Scrub/Shrub								0.179	0.340
Grass									-0.323
Open Water									

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

Figure 6: Proportions of watersheds in each sampled sub-basins with each land-use type. Sub-basins are sorted in order of mean sub-basin B-IBI score (in parentheses).



3.5 B-IBI SCORES AND WATER QUALITY

Water quality data were only available for relatively few of the benthic macroinvertebrate sampling sites (13-26 sites, depending on the water quality parameter in question), and it was therefore not possible to correlate mean sub-basin water quality values with mean sub-basin B-IBI scores. At the site-level, B-IBI scores were significantly (p>0.01), negatively correlated with the following mean base-flow water quality parameters: total phosphorus (r_s = -0.709), total zinc (r_s = -0.741), total copper (r_s = -0.719), alkalinity (r_s = -0.698), conductivity (r_s = -0.670), turbidity (r_s =-0.612), and TSS (r_s = -0.543) (Table 11). Site-level B-IBI scores were not significantly correlated with any of the mean storm-flow water quality parameters measured (Table 12). All of the aforementioned water quality parameters typically increase as a consequence of land-clearing and urban development. However, several of these parameters are significantly auto-correlated (i.e., correlated with one another), which makes it difficult to infer a causal relationship between individual water quality variables and B-IBI score.

In light of the strong correlations observed between site-level B-IBI scores and land-use parameters (Section 4.5.2), we examined the data to determine which water quality values were correlated with land-use data. The most consistent correlations were observed between land-use and conductivity, and between land-use and alkalinity (Table 13). It appears that as watersheds become increasingly urbanized, the conductivity and alkalinity of their watercourses increase.

Table 11: Spearman rank correlation coefficients for site-level B-IBI scores and selected mean base-flow water quality parameters.

	Temp.	Cond.	pH	DO	Alk.	Turb.	TSS	DOC	TOC
B-IBI Score (n=26)	-0.178	-0.670**	-0.159	0.248	-0.698**	-0.612**	-0.543**	-0.438	-0.457
Temperature (n=25)		0.102	-0.350	-0.565**	0.028	0.350	0.323	0.407	0.434
Conductivity (n=25)			0.318	0.000	0.952**	0.517**	0.373	0.522	-0.560*
pH (n=25)				0.722**	0.319	-0.078	-0.191	-0.593*	-0.555*
DO (n=25)					-0.021	-0.397*	-0.398*	-0.621*	-0.698**
Alkalinity (n=25)						0.475*	0.280	0.522	0.544
Turbidity (n=25)							0.872**	0.632*	0.714**
TSS (n=25)								0.451	0.566*
DOC (n=13)									0.967**
TOC (n=13)									

Table 11 - continued i:

	Total P	Total Zn	Total Cu
B-IBI Score	-0.709**	-0.741**	-0.719**
Temperature	-0.178	0.291	0.432
Conductivity	0.449*	0.735**	0.912**
pH	0.053	0.338	0.221
DO	-0.192	-0.115	-0.365
Alkalinity	0.515*	0.703**	0.841**
Turbidity	0.512*	0.568*	0.762**
TSS	0.526**	0.385	0.497
DOC	0.462	0.210	0.566
TOC	0.552	0.224	0.629*
Total P		0.321	0.341
Total Zn			0.871**

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

Table 12: Spearman rank correlation coefficients for site-level B-IBI scores and selected mean storm-flow water quality parameters.

	Cond.	Alk.	Turb.	TSS.	Total P	Total Zn	Total Cu
B-IBI Score	-0.375	-0.232	-0.171	-0.138	0.000	0.206	0.289
Cond.		0.954**	-0.571*	-0.570*	-0.127	-0.100	-0.318
Alk.			-0.629**	-0.626**	-0.073	-0.109	-0.327
Turb.				-0.971**	0.118	0.645*	0.745**
TSS					0.155	0.664*	0.755**
Total P						0.573	0.545
Total Zn							0.918**

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

Table 13: Spearman rank correlation coefficients for site-level land use data and selected mean base-flow water quality parameters.

	Bare Ground/ Asphalt	Bare Rock/ Concrete	Developed - High Intensity	Developed - Medium Intensity	Developed - Low Intensity	Forest	Scrub/ Shrub	Grass	Open Water
Temperature	0.131	0.332	0.210	0.323	0.374	-0.203	-0.407*	-0.160	-0.051
Conductivity	0.643**	0.565**	0.577**	0.652**	0.250	-0.483*	-0.690**	-0.090	-0.174
pH	0.096	0.029	0.030	0.172	-0.057	-0.173	0.092	0.195	-0.241
DO	-0.013	-0.242	-0.172	-0.048	-0.212	0.039	0.205	0.156	-0.218
Alkalinity	0.573**	0.560**	0.522**	0.641**	0.277	-0.477*	-0.675**	-0.183	-0.222
Turbidity	0.377	0.329	0.335	0.398*	0.108	-0.282	0.597**	0.042	-0.232
TSS	0.300	0.258	0.300	0.270	0.150	-0.253	-0.505*	0.106	0.015
DOC	0.429	0.467	0.604*	0.264	0.005	-0.214	-0.511	0.209	0.177
TOC	0.374	0.423	0.538	0.192	-0.093	-0.159	-0.538	0.269	0.127

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

3.6 B-IBI SCORES AND HABITAT VARIABLES

B-IBI scores were significantly ($p<0.05$) positively correlated with all four of the habitat variables measured: dominant ($r_s = 0.192$) and subdominant ($r_s = 0.236$) substrate particle sizes, and left ($r_s = 0.204$) and right bank ($r_s = 0.315$) riparian tree densities (Table 14). The finding that B-IBI score increases with increasing riparian tree density supports our observations regarding the relationships between B-IBI scores and land use: as sub-basins become more developed and their riparian forests cleared, the riparian tree density declines, as does B-IBI score. The finding that B-IBI scores are highest at sites where the substrate is dominated by relatively large particles is also not surprising, because larger particle sizes are expected at sites in good biological condition higher in watersheds, where B-IBI scores are likely to be higher than at more developed, lower-lying sites in streams where the biological condition is low.

Table 14: Spearman rank correlation coefficients for site-level B-IBI scores and selected habitat parameters.

	Dominant Substrate Size Class	Subdominant Substrate Size Class	Left Bank Riparian Tree Density Class	Right Bank Riparian Tree Density Class
B-IBI Score	0.192*	0.236**	0.204*	0.315**
Dominant Substrate Size Class		0.240**	0.168*	0.210**
Subdominant Substrate Size Class			0.082	0.143
Left Bank Riparian Tree Density Class				0.603**
Right Bank Riparian Tree Density Class				

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

3.7 B-IBI Scores and Hydrological Parameters

Site-level B-IBI scores were significantly ($p<0.01$) negatively correlated with instantaneous stream velocity ($r_s = -0.235$), as measured at the late summer time of sampling; the lower the velocity, the higher the B-IBI score (Table 15). Conversely, B-IBI scores were significantly ($p>0.05$) positively correlated with annual mean daily discharge ($r_s = 0.539$), annual maximum daily discharge ($r_s = 0.475$), and annual minimum ($r_s = 0.459$) and maximum ($r_s = 0.752$) instantaneous discharges. Generally, we observed that B-IBI scores increase with stream discharge and watershed area.

Because of the relationship between the amount and type of development in a watershed and changes to the watershed's hydrology (e.g., through the replacement of natural hydrological patterns through patterns impacted by stormwater flows), we investigated the relationships between land-use and hydrology. The instantaneous flow recorded during invertebrate sampling was significantly ($p<0.05$) negatively correlated with upstream watershed surface area ($r_s = -0.241$), percent forest ($r_s = -0.191$), and percent shrub/scrub ($r_s = -0.265$) (Table 16). Instantaneous flow was significantly positively correlated with percent bare ground/asphalt ($r_s = -0.177$), and percent medium-intensity ($r_s = -0.2789$) and high-intensity development. In other words, the larger and less developed the watershed, the lower the late-summer flow, whereas late summer flow generally increased with increasing development within the watershed.

Conventional wisdom suggests that increased conversion of forests to impacted surfaces (i.e., development), increases surface runoff, thereby reducing potential infiltration to active groundwater zones. For the King County region, active groundwater zones are the predominant source of flow for streams in summer and early fall. There are likely many confounding factors that could ultimately contradict this paradigm. Some of the more likely combinations of physical conditions creating this contradiction may include:

- Reduction in vegetation cover, which in turn reduces evapotranspiration demands to the shallow groundwater, and increases the available water supply; this can be very significant in more arid areas, and/or areas with porous soils,
- Hydraulic connections to deeper aquifers not directly impacted by local development,
- Reduction of local well withdrawals resulting from the conversion to higher densities of development and moving to a municipal water supply system, and
- Local stormwater management practices which encourage on-site infiltration and may improve efficiencies beyond natural conditions.

This is not to suggest that increasing development will invariably increase baseflow volumes. Each one of the aforementioned conditions will have varying degrees of influence on the local stream systems. Additionally, there are many conditions not mentioned that could decrease base flow conditions. If all conditions except land use were held constant, base flow volumes would very likely decrease as a result of forest conversion to impacted surfaces.

Various discharge measurements (i.e., mean annual daily Q, annual maximum daily Q, annual minimum daily Q, annual maximum instantaneous Q, annual minimum instantaneous Q) were not significantly ($p>0.05$) correlated with upstream land-use. The exception was annual maximum instantaneous discharge, which was significantly positively correlated with upstream watershed area ($r_s = -0.442$, $p<0.05$). Discharge is generally expected to increase with watershed area, as larger catchments collect more water. However, this does not appear to be the case with the King County data.

Table 15: Spearman rank correlation coefficients for site-level B-IBI scores and discharge (Q) summary data.

	Upstream Watershed Area	Flow Measured During Field Sampling	Mean Annual Daily Q	Annual Minimum Daily Q	Annual Maximum Daily Q	Annual Minimum Inst. Q	Annual Maximum Inst. Q
B-IBI Score (n=155)	0.320**	-0.235**	0.539**	0.243	0.475*	0.459*	0.742**
Upstream watershed area (n=153)		-0.241**	0.361	0.131	0.164	0.302	0.442**
Flow Measured During Field Sampling (n=154)			-0.434*	-0.466*	-0.262	-0.354	-0.057
Mean Annual Daily Q (n=25)				0.851**	0.834**	0.827**	0.823**
Annual Minimum Daily Q (n=25)					0.590**	0.988**	0.507*
Annual Maximum Daily Q (n=25)						0.540*	0.099**
Annual Minimum Inst. Q (n=21)							0.586**
Annual Maximum Inst. Q (n=21)							

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

Table 16: Spearman rank correlation coefficients for site-level land use categories and instantaneous flow and discharge (Q) summary data.

	Instant-aneous Flow (ft/s)	Mean Ann. Daily Q	Ann. Min. Daily Q	Ann. Max. Daily Q	Ann. Min. Inst. Q	Ann. Max. Inst. Q
Upstream Area (acres)	-0.241**	0.361	0.131	0.164	0.302	0.442*
% EIA	0.158	-0.050	-0.013	0.173	-0.011	0.220
% Bare Ground/ Asphalt	0.177*	0.159	0.184	0.263	0.086	0.280
% Bare Rock/ Concrete	0.082	-0.008	-0.029	0.091	0.049	0.221
% Developed - High Intensity	0.221**	0.006	0.030	0.171	-0.104	0.134
% Developed - Medium Intensity	0.278**	-0.114	-0.070	0.094	-0.135	0.066
% Developed - Low Intensity	0.023	-0.056	-0.064	0.023	-0.096	0.110
% Grass	-0.014	0.263	0.314	0.387	0.166	0.223
% Forest	-0.191*	-0.013	-0.070	-0.188	0.013	-0.199
% Scrub/ Shrub	-0.265**	0.303	0.308	0.099	0.333	0.159
% Open Water	-0.095	-0.131	-0.047	-0.299	-0.018	-0.179

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)

4. CONCLUSIONS

The B-IBI provides a useful tool for monitoring ecosystem health in King County streams, and B-IBI scores for the sampled streams and sub-basins are closely related to the amount of urbanization. We were able to provide the following responses to the questions posed by the Greater Lake Washington and Green-Duwamish River benthic SAP (King County, 2002):

Question 1 and 2: Do different watershed sub-basins within the Greater Lake Washington Watershed and Greater Green-Duwamish Watershed differ in terms of biological condition?

The grouping of sampling sites into sub-basins offers a means of simplifying the presentation and discussion of data regarding stream health in King County. Although mean sub-basin B-IBI scores only differed significantly between the sub-basins with the highest (Issaquah, Deep/Coal Basin) and lowest (North Swamp Creeks, West Lake Washington, Black, Duwamish) mean B-IBI scores, mean sub-basin B-IBI scores generally provided an accurate reflection of the overall biological health within each sub-basin. The sub-basins in the best biological condition were Issaquah and Deep/Coal sub-basins, where watercourses generally have “good” or “fair” B-IBI scores. In contrast, all watercourses in the Black, Duwamish, and West Lake Washington sub-basins had “poor” or very poor” B-IBI scores. Other sub-basins have varying proportions of watercourses with B-IBI scores ranging from “very poor” to “good”.

Question 4: Do different land use patterns measured at the sub-basin level affect biological conditions differently within the watershed?

In general, differences in land-use patterns within sub-basins closely reflected differences in B-IBI scores among sub-basins; mean sub-basin B-IBI scores declined with increasing development.

Site B-IBI scores declined significantly as % upstream EIA increased, and as the amount of bare ground/asphalt, bare rock/concrete, and high, medium and low intensity development increased upstream from the sampling site. Conversely, site-level B-IBI scores increased as the amount of upstream forest and scrub/shrub increased. Although it was not possible for us to determine precisely which urbanization-related hydrological or water quality parameters are causing invertebrate community integrity to decline with increasing urban development, B-IBI scores are significantly correlated with conductivity, alkalinity, turbidity, and total suspended solids, as well as stream flow and discharge.

As 2002 was the first year of the benthic program, we were not able to fully address *Question 3: Is the biological condition improving (or declining) over time? Is the trend* *significant?* Upon completion of 2003 benthic data analyses, an initial evaluation of temporal trends will be possible.

We recommend continued use of the B-IBI for monitoring King County streams because, of the different indices tested, the B-IBI appears to provide the most information. If adoption of a “simpler” biotic index was required as a cost-saving measure by King County, we would recommend separating the mayfly, stonefly, and caddisfly (EPT) taxa from benthic macroinvertebrate samples and submitting them to the taxonomic laboratory for analysis, and summing the number of EPT taxa for each site. This would dramatically reduce the amount of taxonomic identification required, but would yield a score which corresponds very closely to the site’s B-IBI score.

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